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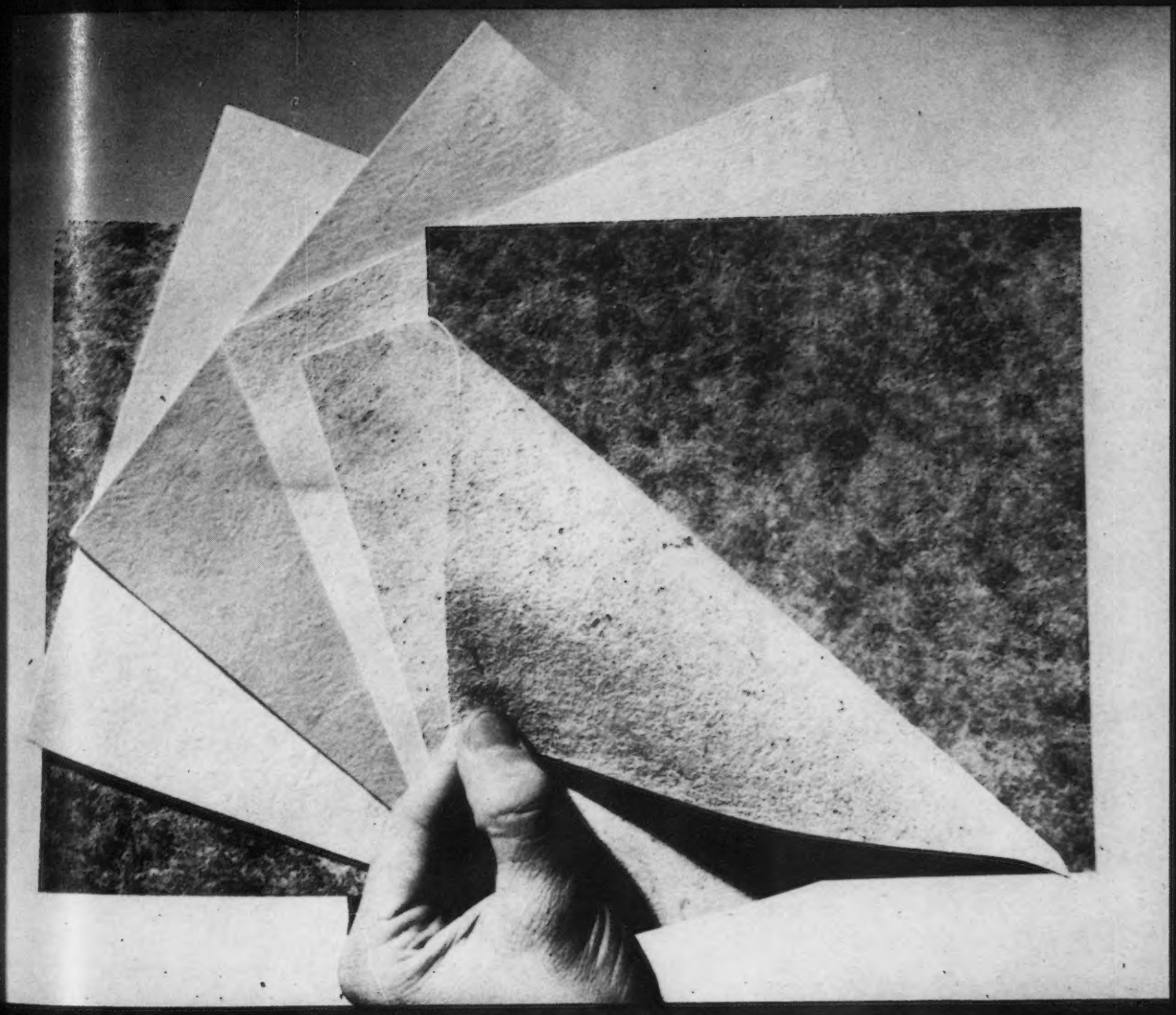

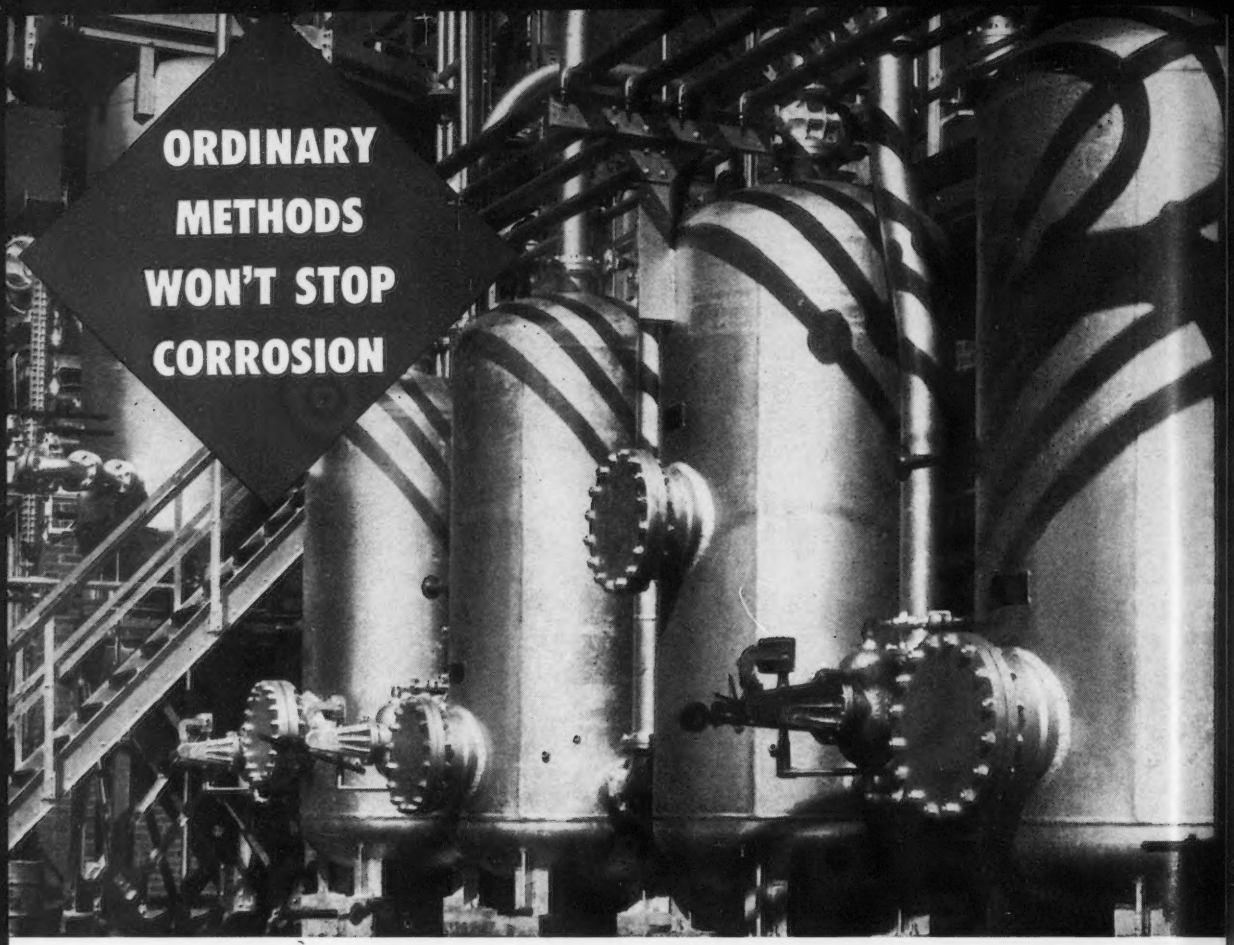

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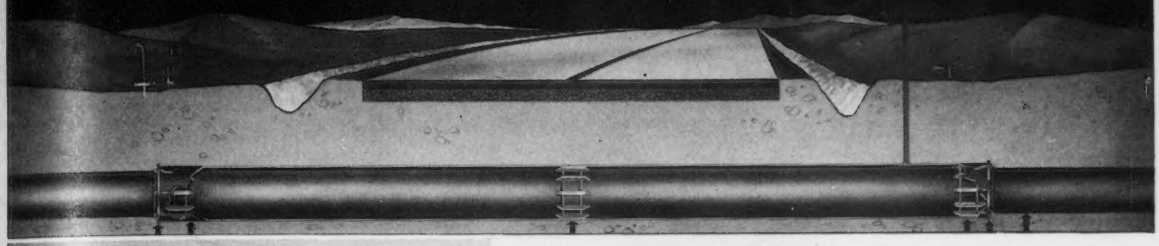

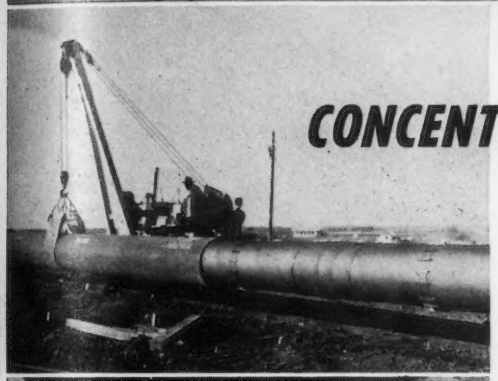

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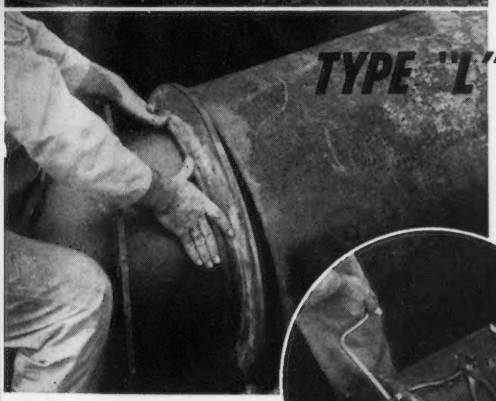

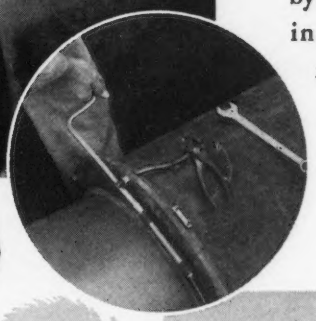

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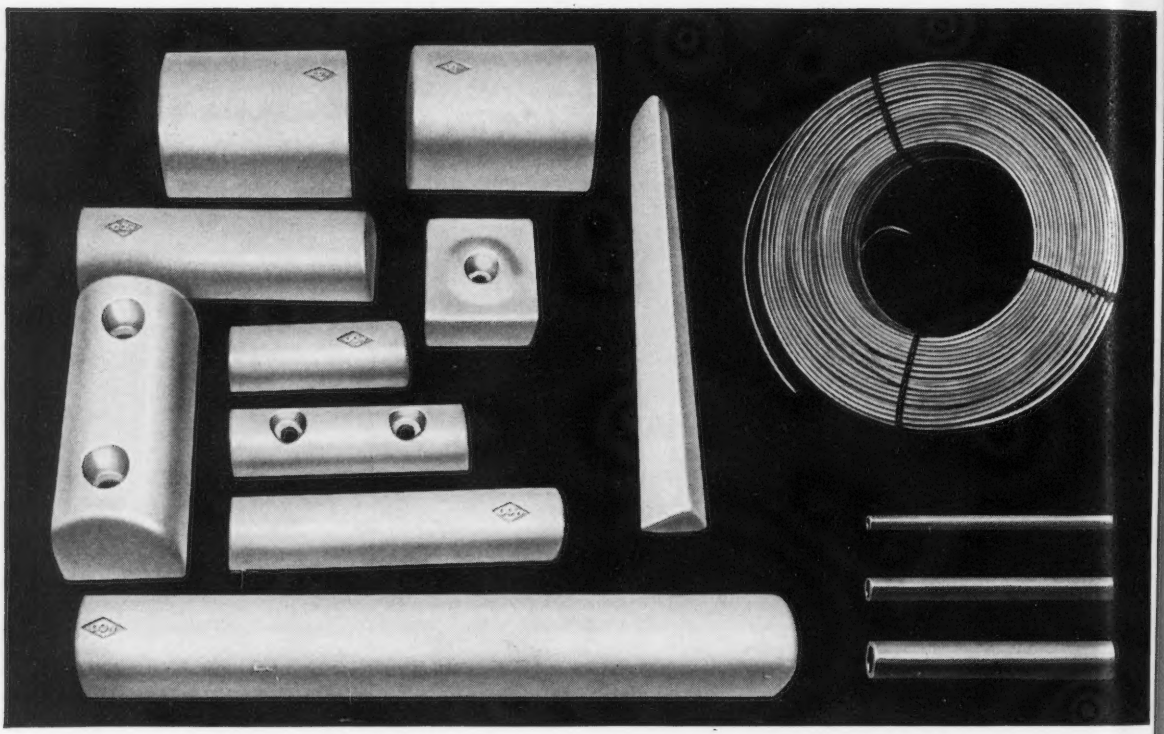

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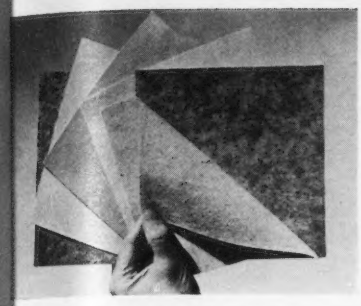

THIS MONTH'S COVER—Paper made from glass fibers is now being made for filtration of hot or cold corrosive gases and liquids. Owens-Corning Fiberglas Corp., Toledo, sells the fiber in wool form to paper companies who process the fiber and make finished paper. The papers are finding use also in specialty electrical laminates, gasketing material and as plate separators in special batteries. Other industrial uses are developing rapidly.

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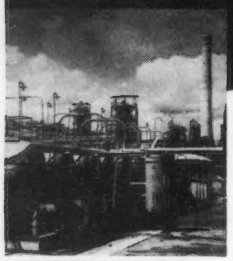

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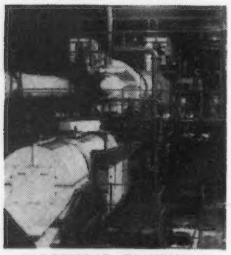

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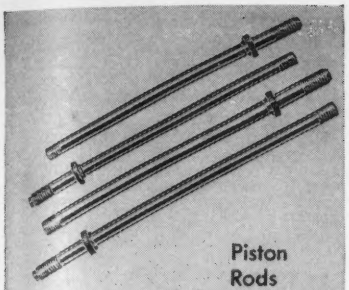

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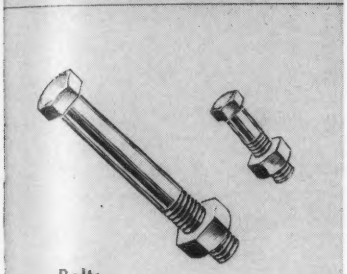

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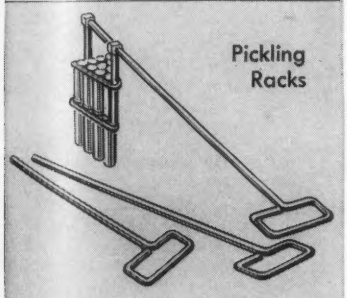

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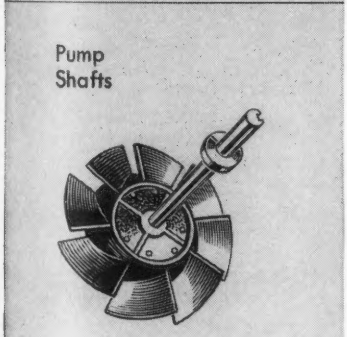

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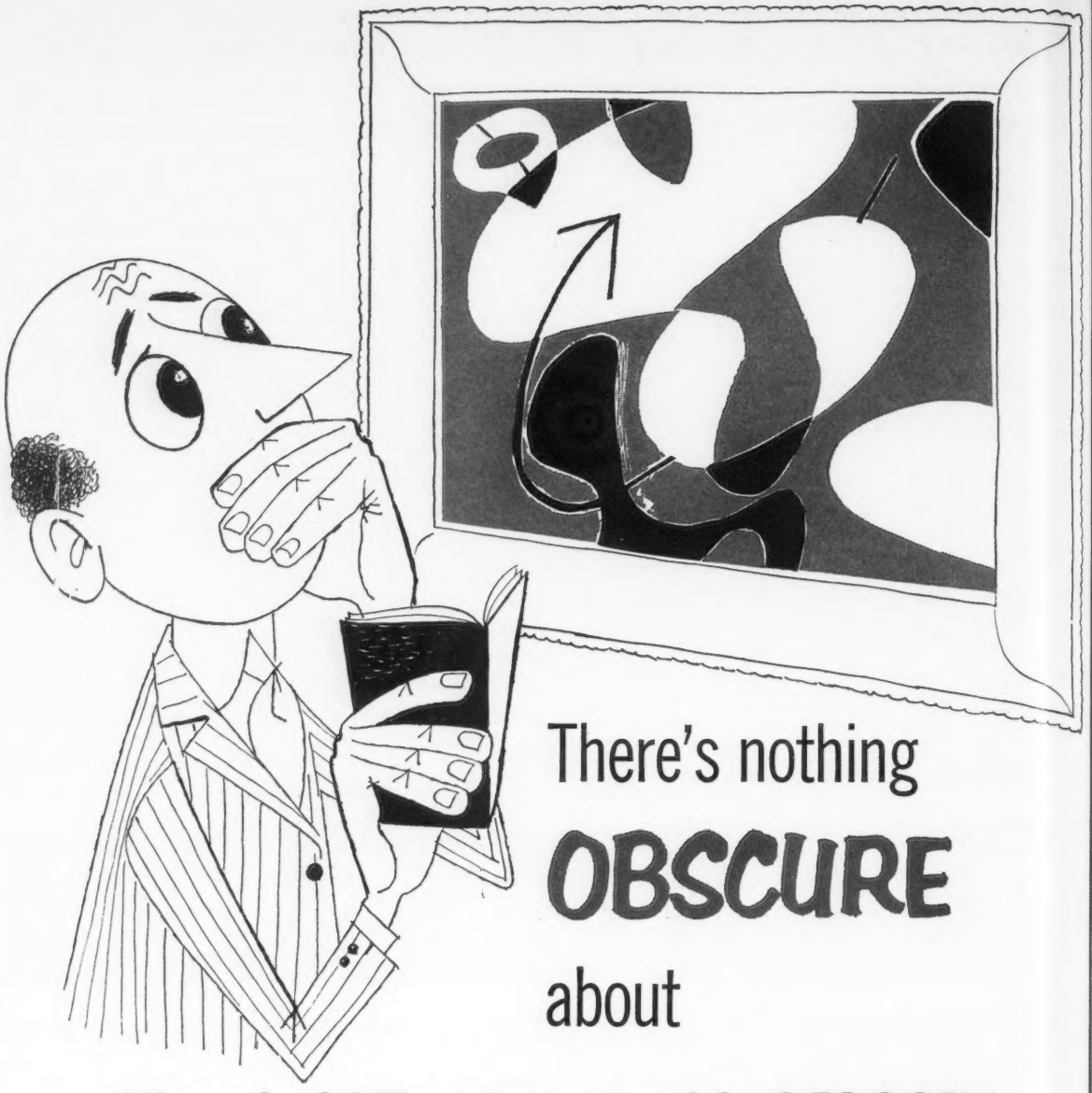

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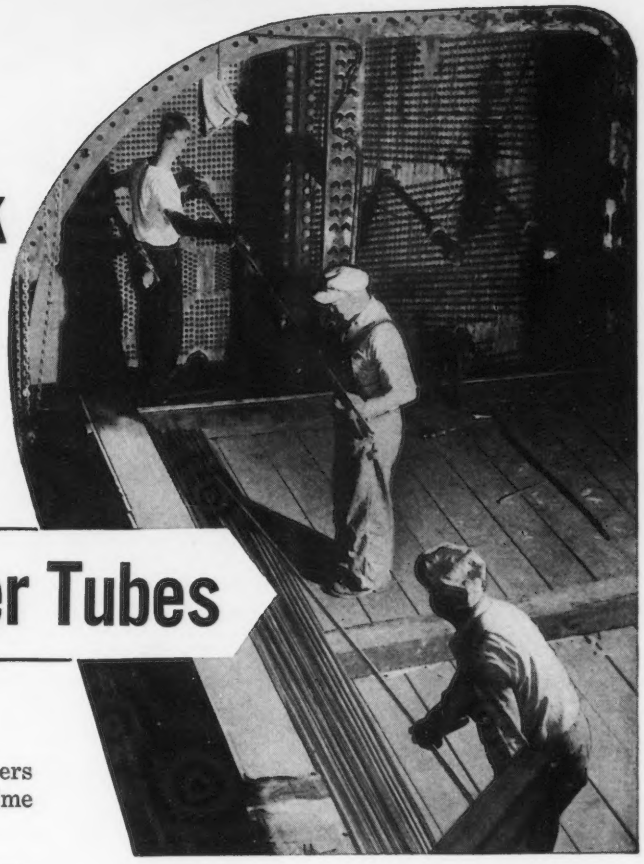

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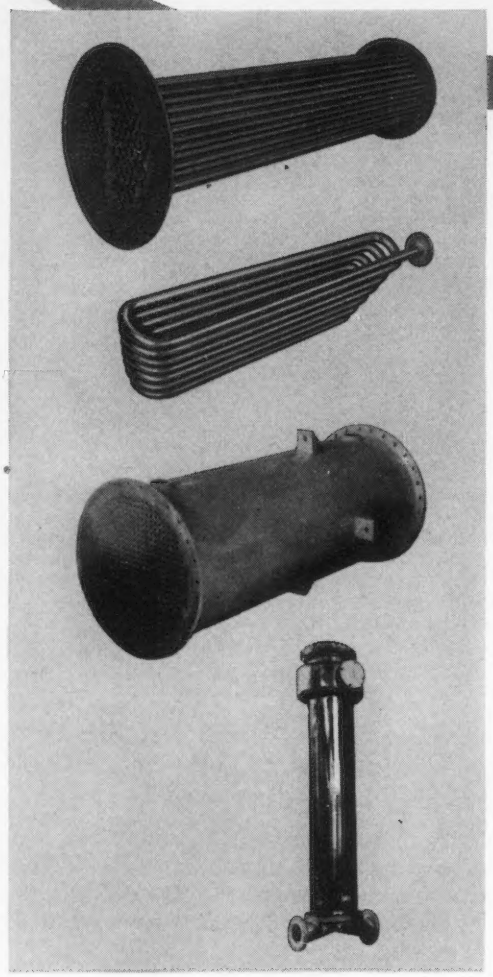

At the left are pictured a group of heat exchangers and heaters in service on widely diverse jobs, in all parts of the country. They have one thing in common —the Carpenter Stainless Tubing that keeps them on the line longer—*when the heat's on for production.

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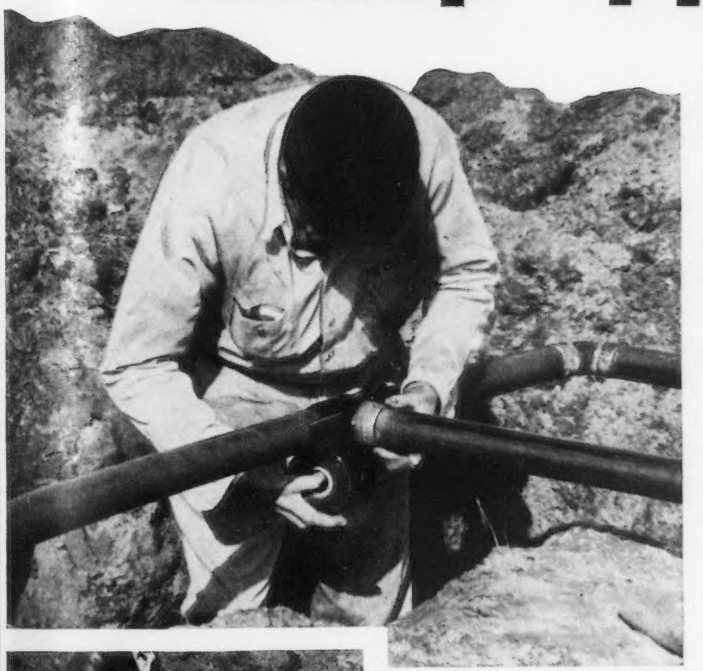

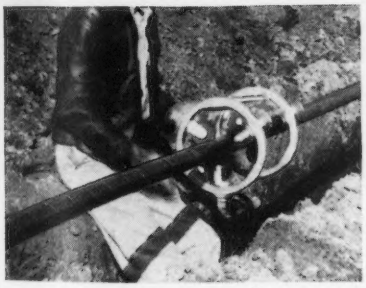

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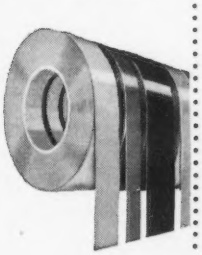

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(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

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Corrosion

OFFICIAL MONTHLY PUBLICATION

National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

1061 M & M Building Houston 2, Texas

Vol. 9 August, 1953 No. 8

Inter Society Corrosion Committee Urges Caution in Use of Unscientific Devices Intended to Prevent Corrosion *

THE INTER SOCIETY Corrosion Committee has become greatly concerned about the hazards which may result from dependence on certain unproven devices for controlling corrosion and scaling. The committee recommends that caution be exercised in the application of such devices, since any failure to give protection may result in serious damage to expensive equipment where a real problem of corrosion or scaling exists.

The Inter Society Corrosion Committee is made up of about thirty-five delegates from major technical societies in the United States and Canada actively concerned with problems of corrosion control and with the scientific reduction of the economic loss caused by corrosion. By means of this word of caution and in accordance with its established objectives the committee seeks to promote the use of the many scientifically sound and effective devices and processes which are presently available and to discourage dependence on unsound and ineffective methods of control.

The committee wishes to draw particular notice to devices which are not based on any understandable scientific principle and which are generally promoted on the basis of testimonials from presumably satisfied customers, unsupported by quantitative data. Special attention is drawn to supposedly scientific explanations which make liberal and incoherent use of such terms as catalysis, magnetism, electronics, radiation, etc. Such "explanations" do not appear to have any basis in scientific fact.

In some cases recommendations are made by manufacturers that grounding wires of electrical circuits, if unfavorably connected to pipes in which the devices are installed, should be rearranged or connected elsewhere. The committee emphasizes that if, because of installation of or after one of these devices has been installed, the electrical circuits are not grounded in accordance with the National Electrical Code, serious impairment of the safety of persons and property may result.

Against this background and in line with its responsibilities the committee then recommends extreme caution in the application of devices for control of corrosion and scaling that are characterized by supposed operation without any apparent basis of sound scientific principles and for which no adequate engineering performance data are available.

* The statement on this page was sent to all delegate members of the Inter Society Corrosion Committee, headquarters offices of governmental agencies and technical societies represented on the committee, with a suggestion it be published in the journals of the societies addressed.

Cathodic Protection of Active Ships In Sea Water With Graphite Anodes★

By K. N. BARNARD,* G. L. CHRISTIE* and J. H. GREENBLATT*

Abstract

Trials on three steel tugs with impressed current cathodic protection systems using graphite anodes are described. The trial results indicate that operation of a graphite anode impressed current cathodic protection system, at reasonable current outputs, requires shielding of the hull around the anodes to obtain uniform current spread at low currents. Paint films have not been found satisfactory as they break down under the relatively high voltage drop (5.5 volts) occurring with graphite anodes. Satisfactory shielding was obtained with vulcanized rubber and results indicate that flame sprayed polymers also may be satisfactory.

Introduction

IMPRESSED current cathodic protection systems have been recently reviewed by Barnard[1] and in his review, the author considered the merits of graphite as the anode material for impressed current systems. The review draws attention to the high ampere hour per pound capacity of graphite, which when coupled with proper mounting techniques would result in a probable anode life of five years and to the availability and cheapness of graphite. Disadvantages cited are: 1) Fragility and poor mechanical strength. 2) Higher driving voltage (over iron, etc.) necessary to overcome the potential between the steel hull and the graphite anode and to electrolize the water so current can flow in the anode-sea water-hull circuit.

It is the purpose of the present paper to discuss in detail the Naval Research Establishment's experience with graphite anodes and to give results of trials on active ships.

Trials with graphite anodes all were made on Glen Class tugs in sea water at Halifax. These ships are 70 feet long, have a wetted area of 2000 square feet and weigh approximately 70 tons. The description and results of trials on the three ships used are given ship by ship, rather than in chronological order. All hull potentials are with respect to a silver-silver chloride electrode and the value for a protected hull established as 820-840 millivolts in earlier work[2,3] was used.

Y. C. GLENBROOK

Experimental. The first trials were made on this ship. Two anodes of National Carbon Company of America's special Na grade graphite for use in sea water were fitted. The anodes were mounted in special steel protective brackets which were welded to the bilge keels of the tug, one to a side. The brackets were lined with rubber sheeting and the anodes were secured to the brackets by bolts bearing on the shoulders of Bakelite inserts threaded into the graphite. The anodes were thus effectively insulated from the hull and given some protection against mechanical damage (Figure 1). An insulated lead from each anode was passed through a watertight gland in the hull and then connected to the positive terminal of the impressed voltage supply. The lead connection into the anode is shown in Figure 2. The negative side of the voltage supply was grounded internally to the hull through a control rheostat and ammeter. The supply for the anodes used at the start of the trial was a bank of 6-volt storage batteries charged from the ship's direct current supply. Before the ship was undocked, the underwater hull was buffed bare of old paint and left unpainted.

Results. The ship was undocked, the cathodic protection system was turned on and recording of the potential of the hull with respect to a silver-silver chloride electrode and the anode current was begun at the time the ship entered the water. It was soon evident from these readings that the hull was not polarizing when 20 amperes or 10 milliamperes per

★ Submitted for publication May 11, 1953.
* Naval Research Establishment, Dartmouth, N. S.

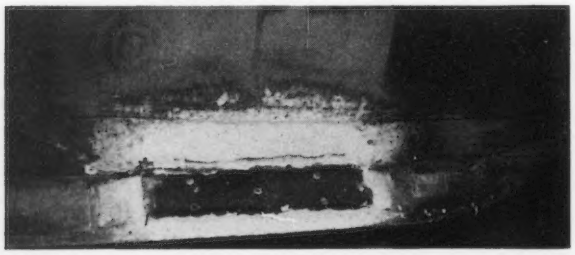

Figure 1a—Port anode on Glenbrook.

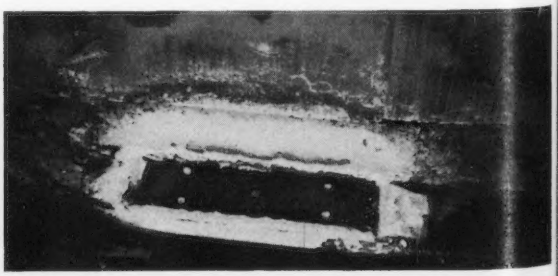

Figure 1b—Starboard anode on Glenbrook.

square foot apparent current density was applied. This value is sufficient to maintain bare steel at a protected potential and it was thought that if the hull were polarized to a protected potential by a high current density from an external source, then the ship's anodes could keep the hull polarized. Accordingly, 200 amperes, or 100 milliamperes per square foot, were passed through sea water to the ship as cathode from a graphite anode 25 feet from the hull, supplied by a welding machine. Potential readings indicated that the hull polarized when the welding machine was on, depolarized when the ship anodes alone were relied upon. A record of the potential-time and current-time readings for the first fourteen days after undocking, is shown in Figure 3. The times when the welding machine was used and other pertinent data are on the graph. The potentials recorded when this machine was in use are the instantaneous open circuit potentials.

From the fourteenth to the forty-third day after undocking, the hull potential of this ship hovered between 625 and 650 with impressed currents of 17 to 27 amperes at 6 volts, i.e., apparent current densities of 8.5 to 13.5 milliamperes per square foot, which values should have been sufficient to polarize bare steel to a protected value. During this period, the battery supply was replaced by a 6-volt automobile generator driven by a suitable motor.

On the forty-fifth day after undocking, a trial was made to determine what current was required to keep the hull at a protected potential. A graphite anode connected to a welding machine was used and when this was held over the side of the tug, two feet from the hull, adequate protection was obtained with a current of 20 amperes. The anodes mounted on the tug were then energized by the welding machine and a current of 150 amperes was required to polarize the hull to the same potential as had been reached with 20 amperes using a single anode at a distance from the hull. This experiment indicated that the current from the ship's anodes could not have been spreading out uniformly and that areas nearer the anodes were receiving a high current density compared to those more distant.

To investigate the type of current distribution actually being obtained, a current survey of the hull was made. The method used was to draw a one foot square steel plate, grounded to the hull, around the hull at different stations along the ship's length, and to measure the current going to this plate through a zero resistance ammeter.[4] Because the test plate and the hull potential at the positions of the hull where the plate was placed were not the same, the current flowing to the plate was measured with the anode current on and again with the current off. The difference was taken as the current going to the plate from the anodes.

Three surveys were made. In the first, a steel plate with its edges masked off by wood and its back face masked off by Ozite cable sealing compound was used. This plate polarized rather badly during the measurements and in the two subsequent surveys a relatively non-polarizing exploring plate was devised.

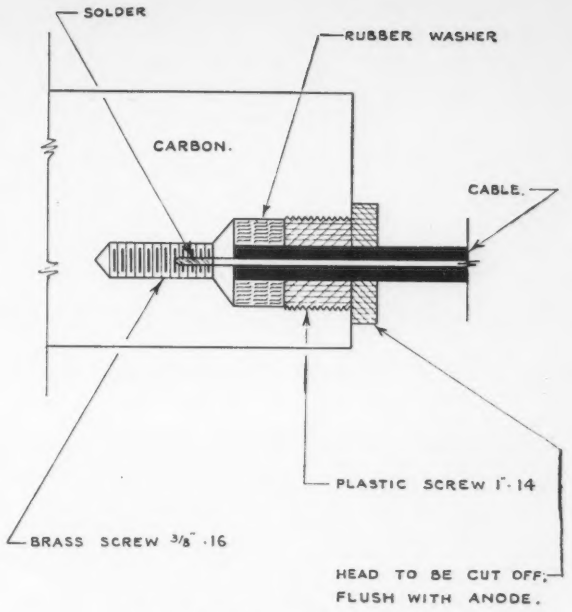

Figure 2—Graphite anode connection.

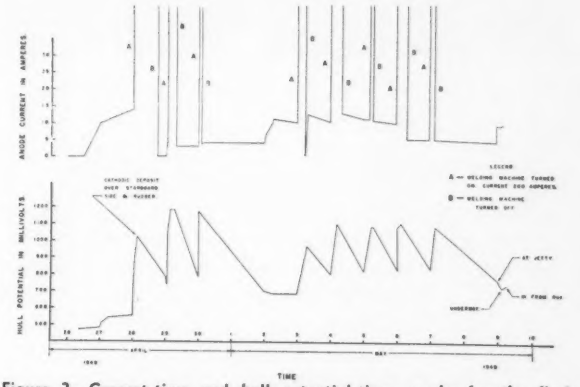

Figure 3—Current-time and hull potential-time graphs for the first fourteen days of protection of Glenbrook.

The new search-cathode consisted of a thin steel box which had four two-inch diameter porous porcelain windows on one face. The edges of the box were masked with wood and the outer back face and steel portions of the windowed face were masked off with Ozite. The interior of the box was filled with a saturated solution of ferrous ammonium sulfate and potassium acid phthalate. The exploring panel in this case was the inside surface of the box in contact with the solution.

The second survey was made after the ship had been out of drydock 113 days and it showed that over most of the hull the exploring panel received 3 to 5 milliamperes. Within 5 feet of the anodes, the current was 12 to 17 milliamperes and it rose suddenly to almost 300 at the anode. Total anode current was 20 amperes. These current readings cannot be changed into absolute current density figures on the hull at the location of the exploring panel, but they are indicative of the order of magnitude expected.

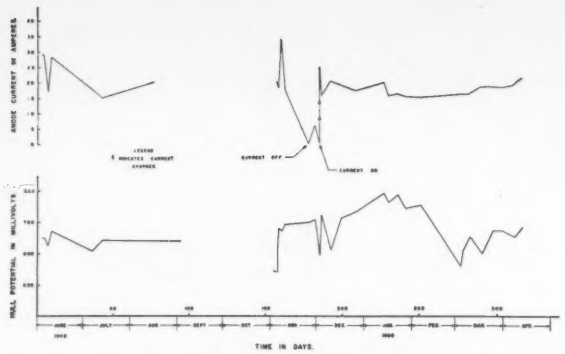

Figure 4—Current-time and hull potential-time graphs for Glenbrook.

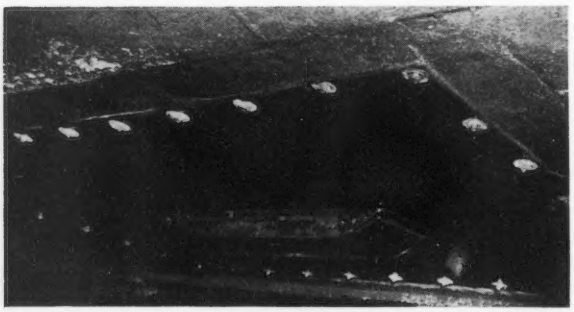

Figure 5—Anode, anode bracket and current shield on Glendyne.

To improve the poor current distribution being obtained, it was decided to shield the area immediately around the anodes with a good grade of paint so 100 square feet of hull, centering on each anode, was buffed bare, degreased, treated with 2 percent phosphoric acid and then given two coats of vinyl paint. The ship was then undocked and the test continued.

With the shielding vinyl patch, the hull potential was higher than before but still did not reach a protected value with reasonable anode currents. A third current survey was made shortly after the vinyl patches had been applied and it was found that the current density was low except near the anode. However, in this case, the area of high current, 12 to 40 milliamperes to the exploring panel, extended over an area 10 feet on each side of the anode. The anode current was 20 amperes.

This survey showed that while the vinyl patch made some improvement, it did not act as an effective current shield. The survey was made in November 1949 and the experiment with Glenbrook was continued until October 1950. During the winter of 1949-1950 when the sea water temperature decreased, the hull polarized and was protected; but when the water warmed up the following summer, the hull was no longer protected even by currents as high as 40 amperes. The record of hull potential and anode current for this ship is shown in Figure 4.

The ship was drydocked in October 1950. As expected from the hull potentials, the ship was rusting. The vinyl coating had broken down in the vicinity of the anodes. These regions and the anode brackets were covered with a heavy cathodic deposit, (Figure 1) which, in some places, was about an inch thick. The remainder of the vinyl patch was brittle and the paint had lost its bond with the underlying steel and could be pulled off in large patches. It was obvious from this inspection that the paint had not acted as a good current shield. The anodes showed about an eighth of an inch of wear on the top face and considerable deterioration of the bottom face. This deterioration of the bottom face was thought to be due to attack by chlorine which had accumulated in pockets under the anode. The anode on the port side had cracked near the lead end, but was still passing current.

Y. C. GLENDYNE

The results with Glenbrook showed that if an impressed current system was to function economically as regards power consumption better current distribution must be obtained from the anode system. To get adequate current spread when using graphite anodes, a high duty insulating shield which will not break down under the applied voltage gradients must be used. The effect of mounting an anode in front of such a shield would be similar to using an anode at a distance from the hull. Accordingly, a second trial was planned in which a steel plate, 6 feet by 9 feet by 0.125-inch, drilled to fit over retaining bolts on the hull, was vulcanized on both sides and around all edges with rubber. A streamlined bracket made to hold a 3-inch by 10-inch by 30-inch graphite anode was also vulcanized all over with the rubber. The anode was secured to, but insulated from, the bracket which was secured to, but insulated from, the hull. Figure 5. Thus there was a double layer of insulating material between hull and anode covering 54 square feet and the anode was in effect removed from the hull. The edges of the rubber shield were all faired with a compound frequently used for streamlining plate edges. Gas escape holes were cut in the sides of the anode bracket prior to vulcanizing to prevent chlorine accumulation on the underside of the anode.

An insulated lead from the anode was passed through the bracket (under an end guard) and shield through a watertight gland into the hull and connected to the positive side of the direct current supply. Power was supplied by a motor generator and the anode output was controlled by a rheostat in series with the generator field.

The hull of this ship had had no previous cathodic protection other than the attachment of small zinc anodes and had corroded severely. The rust on the hull was left untouched, no new paint was applied and the ship was undocked. A record of the hull potential and anode current was kept from the time of undocking and is shown in Figure 6. It can be seen that this tug was maintained at a protected potential except for occasions when the motor generator supplying the current was out of service or the tug was in fresh water. The average current required for protection was about 10 to 12 amperes, an apparent current density of 5 milliamperes per

square foot. At a current drain of 10 amperes, the following voltages across the circuit components were measured: generator to hull, 7.3; anode to hull, 5.6.

The shield was examined when the tug was drydocked four months and eighteen months after it was fitted and no deterioration of the shield was observed. Some deterioration of the rubber over the edges of the bracket was noticed after eighteen months, but it was not considered serious. Anode wear after eighteen months was about ⅛-inch.

This experiment showed that graphite anodes can be used to protect an active ship cathodically when an adequate current shield is placed around the anode and that there is a good probability of obtaining a five-year life from the anode system. A drawback to the above successful trial was the high cost of the anode bracket and shield and it was decided to investigate other likely substitutes for vulcanized rubber. It was thought that polymer materials applied by flame spraying techniques might be suitable current shields and a third trial was started to investigate this possibility.

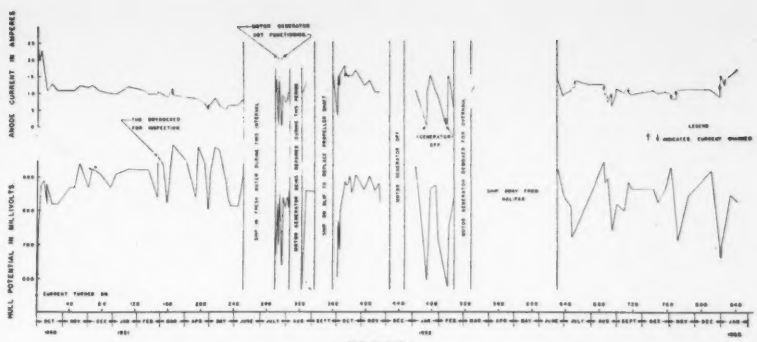

Figure 6—Current-time and hull potential-time graphs for Glendyne.

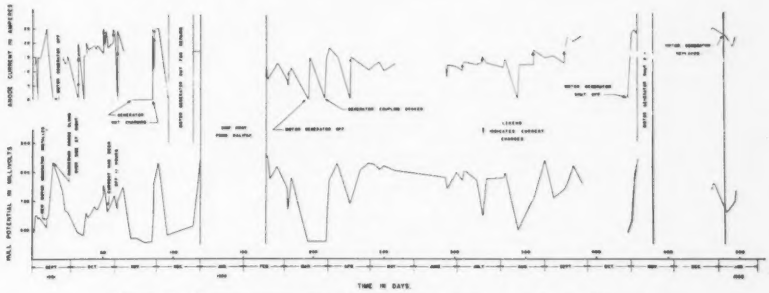

Figure 7—Current-time and hull potential-time graphs for Glenside.

Y. C. GLENSIDE

With the third tug, Y. C. Glenside, a patch 9 feet by 9 feet was sandblasted to bare steel, etched with phosphoric acid and then coated with flame sprayed Polythene. The Polythene was applied with a Schori model L laboratory gun but only ten pounds of Polythene was available for coating. Because of the small quantity of material used, the resulting coating was thinner than those achieved in the usual application of this material, although care was taken to try to get maximum thickness in way of the anode. A graphite anode 6 inches by 30 inches by 3 inches was mounted in a bracket as before, after the bracket had been coated with flame sprayed Polythene. The anode was mounted in, but insulated from, the bracket and the bracket was mounted on, but insulated from, the bilge keel. As before, the current source was a motor generator with a rheostat control. The underwater hull of the tug was buffed bare of old paint, left unpainted and the ship undocked.

A record (Figure 7) was kept of the hull potential and anode current from the time the ship was undocked. It can be seen from this record that part of the time the hull was unprotected because of motor generator failure. Originally, a 7.5-volt 250-watt generator was specified as the supply, but it was not available at the start of the trial and a smaller makeshift motor generator set was used. This proved unable to supply the initial high polarizing current of 25 amperes and it was replaced by a second substitute machine. The second machine supplied sufficient current to polarize the hull and keep it protected, but it was not reliable mechanically and frequent breakdowns occurred. When the hull was protected, the current requirement was somewhat higher than that required for Glendyne.

In July 1952, the tug was drydocked for inspection. It was found that the Polythene immediately around the anode area over an area of 45 inches by 15 inches had broken down, but was fairly intact elsewhere (Figure 8). The coating on the anode bracket was still in good condition although the anode bracket itself was showing signs of stray current corrosion on the streamlined fairing piece bolted to the bracket adjacent to the anode, Figure 8. Current from the anode passed through this piece on its way to the hull, entering and leaving through sharp edges where the Polythene was thin. The tug was undocked, without anything being done to the hull or anode system and the experiment continued. The record, Figure 7, shows that when the motor generator was operating and supplying current, the hull could be protected.

Discussion of Trials

The trials discussed show that active ships can be cathodically protected by impressed current systems using graphite anodes provided a current shield is placed around the anode to insure a fairly uniform

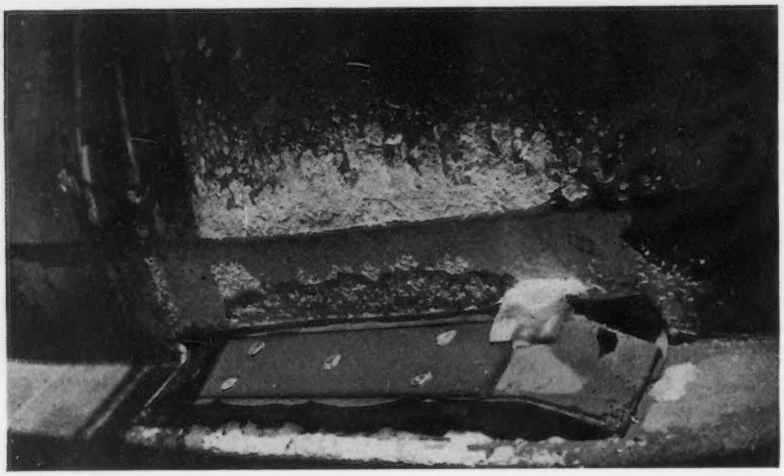

Figure 8—View of anode on Glenside.

current distribution out from the anode. The current shield must be a high duty insulating material, such as a polymer material, must be much thicker than the usual thickness obtained with paint films and it must be bonded more firmly to the underlying steel than a paint film. Vulcanized rubber has proved satisfactory but is costly. Some success was obtained with flame sprayed Polythene but the coating applied was not thick enough to give this material a fair trial.

As pointed out by Barnard[1] in his review on cathodic protection, the results and experience obtained with these tugs is applicable to larger ships and an impressed current system using graphite anodes has been designed for an active ship of 16,000 square feet underwater area and will be fiitted shortly.

The trials also indicate that if alternating current is available on the ships, AC-DC rectifier units would be preferable to motor generators for supplying current to the anodes. Frequent brush and bearing trouble occur with motor generators with the resultant interruption of cathodic protection. If motor generators are used, it is imperative to have a spare on board at all times.

Acknowledgments

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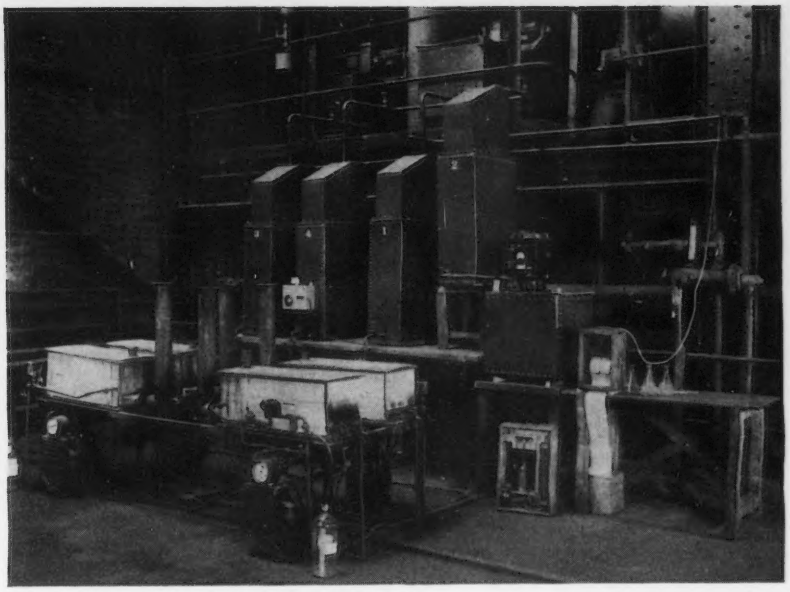

Figure 1—Test apparatus at fuel research station.

Electrical Treatment of Boiler Feed Waters*

By T. F. HURLEY,[1] H. INGLESON,[2] W. J. SPARKES,[1] and R. WILKINSON[2]

Abstract

Two series of tests are reported in which hard make-up water used for small, low pressure steam boilers is examined to determine the effect of electrical treatment of the water on the formation of scale and sludge in the boilers. One test involved boilers specially constructed so they could be taken apart for examination in which two types of electrical treatment devices, one using direct and the other alternating current were applied to two boilers while two other boilers were fed untreated water as controls. The other test involved boilers in commercial use in which tests with and without electrical treatment devices were made. Examination of the sludge and scale residue as to volume, tenacity, constitution and chemical analysis from both boilers receiving electrically treated and boilers not receiving electrically treated water showed wide differences among the boilers. There was no way, the authors concluded, in which these differences could be associated with electrical treatment of the water.

UNTREATED hard water is often used as make-up water for small, low pressure, steam boilers, and the hardness salts are deposited inside the boiler either as a scale or as a sludge. Sludge is to some extent removed during blowing down, but removal of scale involves the shutting down of the boiler and often requires considerable time and labor. Because of these difficulties, many processes have been evolved in which small electric currents are used to induce deposits to form a sludge rather than as scale. These processes are cheap to use since they require no chemicals and only a negligible amount of electrical energy, and they do not call for skilled supervision.

Many devices have been described employing a variety of types of electrode, ranging from the boiler itself, or a specific part of it, to rods or sheets of zinc or other materials fixed in the boiler, in the feed-water heater, or in a separate treatment unit in the feed-water pipe. For most of these devices the electrodes are supplied by some external source with continuous or intermittent direct current, or with alternating current, or with a combination of these at a wide range of voltage and frequency.*

Many reports of successful use of electrical devices for scale prevention have appeared (Cumberland 1915, and others) and in some cases the statements have been supported by photographic evidence (Wehrman, 1937). In 1932 Debaufre (1932) reviewed the literature and experience of the use of electrical processes in the United States. This study, coupled with experimental work, led him to conclude that, though there may be some merit in electrical methods of preventing scale and corrosion in steam boilers, these processes are not effective in all cases. Hubbard (1929) supports this view and Manz (1924)

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* A selection of patent numbers is given at the head of the alphabetical list of references at the end of this paper.

reports similar conclusions from a survey of 20 installations. Splittgerber (1936) found that it is often not possible to explain success or failure of the processes. He considers that it is possible to influence crystal growth by electrical forces and expresses the view that greater success is to be expected when more than half the total hardness is present as bicarbonate.

As has been pointed out by Splittgerber (1937), such extravagant claims have been made by advocates of some of the electrical devices that there has been a very natural tendency to dismiss, as unworthy of serious consideration, all the favorable statements made concerning the value of electrical treatment of boiler feed water. This tendency is further strengthened by the scarcity of factual evidence in support of these statements and by the lack of any clear explanation of the mechanism of the processes.

There is, therefore, a need for more technical information concerning the behavior of electrical equipment, a point which has been well expressed by Partridge (1930) who writes:—

> "Reliable information concerning practical tests of electrical systems for scale prevention is extremely limited. Most of the articles published have very evidently been written by interested parties rather than by impartial observers and do not include essential data. . . . If electrical systems designed to prevent the formation of scale do actually exert some inexplicable influence, it would be to the benefit of all concerned to bring to light definite technical information on the matter. On the other hand, if scale prevention by electrical means is more hypothetical than actual the credulous should be protected from its advocates."

The Fuel Research Station and the Water Pollution Research Laboratory of the Department of Scientific and Industrial Research were accordingly asked by the Ministry of Works and by the Air Ministry to investigate some of these processes.

Two groups of experiments were made. In the first group, carried out at the Fuel Research Station, Greenwich, the boilers developed steam at atmospheric pressure. In the second group, three small boilers operating at a maximum pressure of 15 lb. per sq. in. were used; these were placed at the disposal of the Department, for purposes of the tests, by the Chief Mechanical and Electrical Engineer, Air Ministry Works Directorate.

Group I Tests

The type of boiler commonly used in small installations has many surfaces which are difficult to reach during cleaning. The experimental boilers at the Fuel Research Station were therefore made so that they could be dismantled for cleaning. Four boilers, 30 in. long, 10½ in. wide, and 12 in. deep, were made of light mild steel plate, and the sides and removable lid were covered externally with asbestos sheet. The normal water level in the boiler was 6 in. below the lid and 3½ in. above the three fire tubes which passed longitudinally through the water space. Each tube was 2 in. in diameter and was heated by a single gas jet. The gas supply was measured and adjusted to give a rate of evaporation of about 14 lb. of water per hour.

Two kinds of proprietary electrical treatment units were used in the first test. One, using alternating current, consisted of 21 elements fitted into the base of a wooden box, open at the top and mounted within a small metal tank. Each element consisted of a carbon electrode surrounded by a concentric ebonite cylinder. The water to be treated was delivered into the box and passed through the annular spaces between the carbon electrodes and the ebonite cylinders, and into the metal tank which served as the second electrode. The total current supplied was about 280 microamperes, obtained from the mains through a transformer and variable resistance. The unit employing direct current consisted of a short length of wide metal pipe, flanged at one end and fitted into the feed-water pipe by means of screwed joints. An electrode, which consisted of a hollow cylinder closed at one end and having a number of narrow slots along its length, was mounted inside the wide pipe by means of an insulated flange. The water to be treated passed through the slots and out of the unit. Electricity was supplied from the mains through a transformer, rectifier, and variable resistance. The positive lead was joined to the slotted electrode, and the negative to the outer cylinder, which was earthed; the current used was about 90 microamperes.

The assembled equipment is seen in Figure 1. Water supplied to the boilers was measured by weighing and was discharged to four stock tanks, one for each boiler. From the stock tanks the water flowed by gravity through a control valve to a float chamber in the feed pipe at the side of the boiler. Screwed mild steel pipe was used throughout in conveying the water. When electrical treatment was used, the equipment was fitted between the stock tanks and the float chamber. The makers were consulted with regard to the method of fitting up the equipment and the setting of the current. At their request, the equipment using direct current was bonded electrically with the station's water main.

Filtered samples of the various feed waters were collected daily, and samples taken during a fortnight were mixed to provide a composite sample for analysis. The concentration of dissolved solids in the boilers was allowed to rise to a chosen value, which was maintained by a daily check. The boilers were blown down as necessary and the water, and any suspended matter removed with it, was collected, stored, measured, and later analysed. Table 1 gives the volumes and average results of analysis of the boiler feed waters and blowdown waters. At regular intervals the boilers were shut down for inspection, and at the end of 100 days they were allowed to cool down completely and were examined and cleaned.

The criterion used to determine the effect of treatment was the ease with which deposits could be removed from the boiler. In cleaning a boiler, the contents were first drained off, collected, and measured. The inside of the boiler was then washed down by a jet of water, and solid thus removed was separated, dried and weighed. After this the base of the boiler was detached, and the boiler was cleaned

with a steel spatula and by tapping it lightly with a scaling hammer. Deposits removed in this way were classified as easy to remove, but deposits which needed a heavy scraper to remove them were classed as difficult to remove.

Three tests were made with these four boilers, but the results for one boiler in each of Tests 1 and 2 are outside the scope of this paper as Boiler No. 3 in Test 1 received softened water, and Boiler No. 2 in Test 2 received water treated in an "activator." In the first test, the concentration of solids in the boiler water was allowed to rise to 14,000 parts per million, but in the second and third tests it was maintained at about 7000 ppm. Between the second and third tests the boilers were modified slightly, and a hopper bottom was provided in which sludge could collect where it was not disturbed by the circulation of water in the boiler. The various waters were supplied to different boilers in successive tests, to reduce as far as possible the influence on the result of chance variations in the construction or operation of the boilers. Two methods of electrical treatment were used in the first test, and the scale deposited in the boiler which received untreated water was the most difficult to remove. The second test, made in a similar way, failed to confirm this result and a third test was therefore made, with two boilers receiving untreated water and two boilers receiving water treated in the direct current equipment; but this also was inconclusive.

In Table I the weights of sludge and easily removable scale are given as percentages of the total solid matter deposited in the three tests. At the end of the first test the fire tubes were covered by hard scale, and a softer scale overlying hard scale had formed on the sides of the boiler. These scales were firmly adherent when the water had not been treated, but in boilers which had received electrically treated water a portion of the scale had flaked off the metal or could be chipped off in large pieces. The percentage of the total deposit classified as "easily removable" was considerably higher in the two boilers using water treated electrically than in that using untreated water.

At the end of Test 2, hard scale had formed on the tubes in all the boilers and, as in Test 1, there was a softer scale on the sides. The scale showed less tendency to flake from the metal. Deposits in the boilers were classified in the way used in Test 1, and in addition the times needed to clean different parts of the boilers down to bare metal were recorded (Table I). The proportion of deposit classified as easy to remove was about the same in all three boilers, but the time taken to remove solids completely from the boilers which had received electrically treated water was longer than that required for the boiler receiving untreated water. The times taken were not in proportion to the proportion of hard scale because, in cleaning to bare metal, thin scales were sometimes more difficult to remove than thicker scales.

Scale which had a tendency to flake from the metal was again found in some parts of the boilers after Test 3, but there were large differences between the deposits found in boilers which had received the same water. In two boilers scale was much easier to remove than in the other two, but each pair included one boiler which had received treated water and one

TABLE I

Results of Analyses and Measurements Made in Group I Tests

Test No.	1			2			3			
Boiler No.	1	2	4	1	3	4	1	2	3	4
Treatment of water	None	A.C.	D.C.	A.C.	D.C.	None	D.C.	D.C.	None	None
Weight of water used (lb.)	32,872	22,582	32,796	33,554	33,646	33,549	31,592	31,649	31,323	31,564
Period of test (days)	100	70*	100	100	100	100	100	100	100	100
AVERAGE RESULTS OF ANALYSIS AND WEIGHTS OF WATER SUPPLIED TO BOILERS										
Parts per Million:										
Alkalinity (as $CaCO_3$)	205	206	202	207	205	213	200		210	
Total hardness (as $CaCO_3$)	274	276	265	238	253	253	260		270	
Calcium (as Ca)	99	98	99	101	98	109	105		114	
Magnesium (as Mg)	15	14	14	18	16	16	18		18	
Silica (as SiO_2)	10	9	10	12	13	13	13		13	
Chloride (as Cl)	35	35	35	36	36	35	34		34	
Sulphate (as SO_4)	69	66	66	71	72	74	76		76	
Total dissolved solids	402	402	392	404	412	408	405		412	
AVERAGE RESULTS OF ANALYSIS OF BOILER WATER AT END OF TESTS AND ACCUMULATED BLOWDOWN WATER										
Parts per Million:										
Alkalinity (as $CaCO_3$)	74	96	69	68	68	68	63	73	65	73
Total hardness (as $CaCO_3$)	3,480	3,410	3,340	2,390	2,650	2,650	2,210	2,262	2,306	2,562
Calcium (as Ca)	1,360	1,310	1,302	975	1,010	1,025	863	860	890	1,010
Magnesium (as Mg)	68	76	68	72	69	69	66	69	76	91
Silica (as SiO_2)	9	9	9	10	12	11	19	19	19	20
Chloride (as Cl)	3,830	4,150	3,730	1,650	1,760	1,680	1,303	1,428	1,436	1,515
Sulphate (as SO_4)	2,340	2,240	2,590	1,710	1,610	1,710	....	....	....	....
Total dissolved solids	14,200	14,426	13,260	7,320	7,840	7,500	6,100	6,170	6,000	6,240
PARTICULARS OF SOLIDS REMOVED FROM BOILERS AT END OF TESTS										
Weight of solids collected (lb.)	9·1	5·9	9·0	8·7	9·3	9·0	6·5	7·8	8·5	7·2
Weight of solids easily removable (lb.)	1·1	3·2	8·2	6·1	7·0	6·8	6·4	4·2	8·0	4·6
Easily removable solid as fraction of total (percent)	12	54	91	70	75	76	98	54	94	64
Time taken to clean boilers (min.)	....	....	....	86	121	63	180	172	298	174

* Boiler No. 2 was shut down because of an accident, and later restarted.

boiler which had received untreated water. The time taken to clean one of the boilers supplied with untreated water was much longer than that needed for any of the other three boilers.

At the end of Test 1, six samples of deposit which had proved easy to remove and seven samples which had proved difficult to remove were analysed, with the results given in Table II. The composition of both types of scale varied widely, and the difference between the average composition of scale in the two groups is not statistically significant.

Petrological examination, by the Geological Survey and Museum, of samples from Test 1 showed that the main constituents of the scales were anhydrite, aragonite, and calcite. Calcium carbonate in scale from boilers fed with untreated water and with water treated by direct current was predominantly in the form of aragonite; in those boilers which had been supplied with water treated by alternating current it was predominantly calcite. It was not possible to correlate the presence of any form of any mineral with ease of removal of the deposit, except that where stout calcite crystals were present the scale was easy to remove.

Selected samples of deposit collected during the third test were examined by the X-ray diffraction method, to identify the crystalline compounds present. Samples from both boilers receiving treated water, and from one boiler (No. 3) receiving untreated water, were composed mainly of a mixture of calcium carbonate in the form of calcite and calcium sulfate in the form of anhydrite. In Boiler No. 3 the maximum thickness of the scale was less than that in the other boilers and the carbonate and sulfate were intimately mixed, whereas in other scales they showed a greater tendency to be deposited in layers. The scale derived from Boiler No. 4 (which also received untreated water) was markedly different from that from the other boilers, the bulk of the carbonate being in the somewhat rare crystalline form known as μ-$CaCO_3$ or vaterite, and the major part of the sulfate in the form of hemi-hydrate. Although a specific search for aragonite was made, it was not identified in any of the 25 samples examined.

All samples of scale contained, on the surfaces next the metal, extremely thin hard black layers. These layers were composed mainly of magnetite, and there is little doubt that they were oxide scale from the surface of the boiler tubes. Since practically the whole of the scale which detached itself from the tubes contained this layer intact, it follows that the surface over which the fracture occurred lies beneath the surface of the boiler tube, and the oxide layer is weaker than the scale itself. This may, of course, have an important bearing upon the ease of removal of the different scales.

TABLE II

Comparison of the Constituents of Samples of Scale, Classified According to the Ease of Their Removal From the Boiler in Test No. 1 (Group I Tests)

PERCENT OF DRY WEIGHT	Scale Removed With Difficulty (Average of 6 Samples)			Scale Removed With Ease (Average of 7 Samples)		
	Highest	Mean	Lowest	Highest	Mean	Lowest
Carbonate (as $CaCO_3$)	68.3	57.3	51.1	73.9	55.9	39.8
Sulphate (as $CaSO_4$)	38.9	29.8	15.0	49.9	27.5	3.9
Calcium (as Ca)	34.2	30.0	21.8	33.1	28.1	22.6
Magnesium (as Mg)	5.0	2.1	0.4	5.4	3.5	1.6
Iron (as Fe)	4.7	2.0	0.9	6.9	2.3	0.6
Material insoluble in hydrochloric acid	5.3	2.4	0.8	6.9	3.5	0.6

Conclusions from Group I Tests

It will be seen from Table I that there were considerable differences in the results of the three tests in Group I. It is clear from Table III, which shows the average proportion of loose scale or sludge deposited in the boilers, that the difference due to the use of the alternating current treatment is without significance. Statistical analysis indicates that the apparent improvement due to the use of the direct current treatment is also without significance. The general conclusion, therefore, is that electrical treatment of the feed water did not have any significant effect on the ease of removal of the deposits in the boiler.

Group II Tests

Arrangements were made to carry out experiments on two boilers (Boilers A and B) supplying steam to a canteen at an airport. The boilers were of a vertical cross-tube type, and each had a rated output of 250 lb. of steam per hour at 15 lb. per sq. in. working pressure. In this type of boiler (Figure 2) the combustion chamber is completely enclosed in the main boiler shell and the water tubes are connected diametrically across the combustion chamber. The boilers were 8 ft. high and 3 ft. in diameter, with one lower and two upper cross tubes, all 6 in. in diameter. At the working level, each boiler held about 100 gallons of water. In some experiments a third boiler (Boiler C) was also used. It was supplied with water from the same source as Boilers A and B but was in a separate boiler house and served another canteen. It was of a similar type to Boilers A and B but was smaller, having only one cross tube and a rated output of 150 lb. of steam per hour at 15 lb. per sq. in. working pressure. Water was supplied from an overhead tank to the boilers through separate pipes, water meters, intermediate supply tanks, automatically controlled feed pumps, and feed pipes. Boilers A and B were connected to a common steam main and were operated as far as possible under the same conditions. They were on load from about 6 a.m. to 9 p.m. each day, during which time the steam pressure varied over the range 3 to 15 lb. per sq. in. Between 9 p.m. and 6 a.m. little steam was produced. During the steaming period, the boilers were operated and all readings were taken by the airport staff who normally operated the boilers.

TABLE III

Average Proportion of Loose Scale or Sludge Deposited in Boilers in Group I Tests

TREATMENT OF FEED WATER	Average Proportion of Easily Removable Deposit (Percent)	Difference Between Average Proportions With Treated and Untreated Water
None	61.5	.....
Alternating current	62	+ 0.5
Direct current	79.5	+18.0

During each experiment the volume of feed water to each boiler was measured, and samples of it and of the boiler water were collected at intervals and analysed; results are given in Tables IV and V. Water and sludge blown down from the boilers were collected in separate tanks. To maintain as far as possible the same conditions in each boiler, the concentration of dissolved solids in the boiler water was allowed to rise in each experiment to about 3,500 ppm (about 250 gr. per gal.) and was kept near this value by blowing down. This object was not achieved to the degree desired since considerable trouble was caused by occasional failure of the water level controller, leakage from the blowdown valves and other mishaps. Some indication of the influence of these factors is given by the particulars in the last column of Table V, showing the concentration of dissolved solids in the boiler water at the end of the tests. In most experiments the volumes of water supplied to the boilers were approximately the same; Boiler C, though smaller, evaporated about the same volume of water as did each of the other boilers.

In the first two of the seven experiments, an attempt was made to compare the deposits from treated and untreated water, by operating one boiler with electrically treated water at the same time as the second boiler was receiving untreated water. To do this, direct-current equipment, of the same type as that used in Group I tests, was fitted in the feed pipe to Boiler A between the intermediate supply tank and the feed pump. It had been stated by the makers of the equipment that the effects of treatment are sometimes observed in a boiler which, though connected to the same water main, does not receive water directly treated by the electrical equipment. In the first experiment, to reduce possible interference from this source, parts of the supply pipes from the overhead

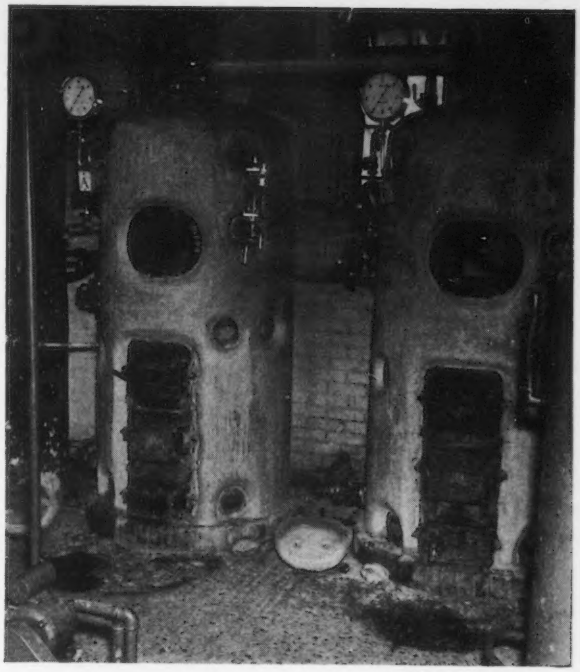

Figure 2—Boilers used at an airport.

TABLE IV

Average Results of Analysis of Water Supplied to Boilers at an Airport

Experiment No.	1	2	3	4		5		6		7
Boiler No.	A & B	A & B	A & B	A & B	C	A & B	C	A & B	C	A & B
Treatment	+ −	+ −	−	−	−	−	−	+	+	+
Period of test (days)	90	66	59	90	90	87	87	94	94	88
Parts per Million:										
Alkalinity (as $CaCO_3$)	249	195	181	194	192	210	215	174	187	237
Total hardness (as $CaCO_3$)	279	230	198	214	215	230	233	195	206	260
Calcium (as Ca)	109	89	80	83	84	93	94	77	82	102
Magnesium (as Mg)	1·7	1·9	1·9	1·9	1·9	2·4	2·4	1·6	1·5	1·5
Silica (as SiO_2)	26	37	31	34	32	38	38	36	35	29
Chloride (as Cl)	9·5	12·6	10·2	10·3	10·3	10·8	10·8	12·7	12·2	14·2
Sulphate (as SO_4)	11·1	11·4	11·4	11·9	11·4	11·7	11·3	11·5	12·4	14·0
Total dissolved solids	318	278	249	270	264	287	292	245	255	316
PH value highest	8·0	8·0	8·0	8·0	8·0	8·2	8·0	8·2	8·1	8·4
PH value lowest	8·0	7·6	7·7	7·6	7·7	7·8	7·7	7·9	7·3	7·7

TABLE V

Total Volume of Water Supplied to Boilers During Tests, and Composition of Boiler Water at End of Tests
Experiments at an Airport

Experiment No.	Boiler	Volume of Water Supplied (Gallons)	COMPOSITION OF BOILER WATER AT END OF TEST—(Parts per Million)							
			Alkalinity (as $CaCO_3$)	Total Hardness (as $CaCO_3$)	Calcium (as Ca)	Magnesium (as Mg)	Silica (as SiO_2)	Chloride (as Cl)	Sulphate (as SO_2)	Total Dissolved Solids
1	A	15,776	35	1,012	391	53	180	878	111	3,244
1	B	14,945	35	945	366	54	180	822	114	3,030
2	A	12,670	70	900	304	68	450	460	92	2,300
2	B	13,518	50	1,500	586	78	450	1,070	117	4,300
3	A	10,985	33	450	1,868	38	700	284	45	1,400
3	B	10,405	40	900	365	68	700	640	84	3,174
4	A	19,370	32	831	328	57	315	646	116	2,800
4	B	19,161	59	820	332	58	330	592	106	2,609
4	C	19,340	148	478	195	32	260	253	45	1,374
5	A	18,795	44	845	338	54	400	580	100	2,652
5	B	21,599	63	1,045	415	61	420	724	129	3,200
5	C	21,971	80	620	242	51	400	434	77	1,872
6	A	13,225	26	678	259	60	500	443	118	2,166
6	B	13,397	34	988	394	70	550	703	217	3,020
6	C	18,414	62	619	240	58	500	387	81	1,992
7	A	18,330	40	870	345	67	400	692	154	2,710
7	B	16,255	45	600	240	57	400	408	156	1,770

tank were replaced by rubber hose, and the two feed water and boiler systems were insulated from one another at all points except the common steam main. The boiler and electrical unit were effectively earthed. The metal pipe between the electrical equipment and the boiler was cut in two places and insulating material was inserted so that, if desired, electrical tests could be made during the experiment. These insulated sections were, however, bridged by banding wires giving electrical continuity between the electrical equipment and the boiler.

The installation was inspected by the makers of the electrical equipment before the start of the tests and, although they appreciated the reason for the unusual method of connecting up the equipment, they expressed a decided preference for the normal all-metal installation. Because of its possible effects on the treatment, the insulation was completely replaced by metal pipe and screwed connections before Experiment 2 took place. These metal pipes now earthed the treatment unit and the boilers to the water mains, and the separate earth connection, necessitated by the insulation, was removed. After Experiment 2, when there was a possibility of interaction between the boilers, no further experiments were made in which one boiler received treated water at the same time as the other received untreated water. To observe the type of deposit formed in untreated water, Experiments 3, 4 and 5 were made, in which no treatment was given to the water supplied to any of the boilers. Boiler C was included only in Experiments 4, 5 and 6.

The feed water to all the boilers was again treated by the electrical equipment during Experiments 6 and 7. The makers of the electrical equipment inspected the installation before Experiment 6 began, and tested the feed pipes for electrical continuity. Since the units had been out of use for some time, and they were considered by the makers not to be in good order, they were replaced by new ones which were fitted under the supervision of the makers.

Before the experiments began, existing scale was removed from the boilers by chipping and scraping and by using inhibited acid. At the end of each experiment the interiors of the boilers were inspected as thoroughly as possible, photographs were taken, and samples of deposit were collected. To obtain some measure of the amount of scale formed in the boilers and the proportion which could be removed easily, each boiler was usually cleaned in two stages. In the first place, loose scale was dislodged by light chipping with a steel bar and by brushing with a wire flue brush. The boiler was then hosed down, and flakes of scale and sludge were washed and scraped from the mudholes into a metal tray. After settling most of the water was run off and the solid was dried and weighed. Since much of the interior of the boiler could not be reached by the tools needed to dislodge adherent scale, the second stage of removal consisted in treating the boiler with inhibited acid. The used acid was collected and its volume and content of calcium were determined. The proportion of calcium in the loose scale and sludge removed in the first stage was also determined, and it was thus possible to compare the weight of calcium deposited as loose scale with the weight deposited as adherent scale. If it is assumed that the composition of the two types of scale is approximately the same (see Table II), then the weight of calcium (expressed as calcium carbonate) will give an approximate measure of the actual weight of deposit in the boilers.

Details of the nature of the deposits at the end of each experiment are given in Table VI and are discussed below.

Experiments 1 and 2 (Boiler A with treated water; Boiler B with untreated water):—

At the end of Experiment 1, a layer of fairly soft granular scale which was flaking away in places covered the interior of both boilers. There was no sludge and no significant difference between the boilers. In this experiment an interim inspection was made after 4½ weeks' steaming, and at that time the flaking of scale had started in Boiler A but not in Boiler B.

In Experiment 2 the type of deposit in the two boilers was again similar, but was very different from that in Experiment 1. Both boilers contained a considerable amount of soft sludge which settled in the base, on the firebox crown, and in the cross tubes. The only scale observed was a small patch near the feed-water inlet. Irregularities in the metal surface were visible, and slight hollows were filled with fine sludge which could be removed with a soft brush.

TABLE VI

Effect of Treatment of Feed Water with Direct Current on Amount and Condition of Scale and Sludge Deposited in Boilers at an Airport

Experiment No.	Boiler	Treatment of Feed Water	Period of Experiment (Days)	Weight of Calcium (as $CaCO_3$) (lb.)			Proportion Removable As Loose Scale or Sludge (Percent)
				In Loose Scale or Sludge	In Adherent Scale	In Total Deposit	
1	A	Treated	90	7·9	51·2	59·1	13
1	B	Untreated	90	5·1	53·5	58·6	9
2	A	Treated	66	15·2	13·1	28·3	54
2	B	Untreated	66	15·9	12·1	28·0	57
3	A	Untreated	59	8·0	16·8	24·8	32
3	B	Untreated	59	18·8	10·9	29·7	63
4	A	Untreated	90	16·2	30·0	46·2	35
4	B	Untreated	90	29·6	11·5	41·1	72
4	C	Untreated	90	31·9	10·3	42·2	76
5	A	Untreated	87	12·5	26·9	39·4	32
5	B	Untreated	87	31·5	5·4	36·9	85
5	C	Untreated	87	29·5	7·4	36·9	80
6	A	Treated	94	13·9	15·8	29·7	47
6	B	Treated	94	19·8	5·5	25·3	78
6	C	Treated	94	25·8	6·1	31·9	81
7	A	Treated	88	13·6	30·4	44·0*	31
7	B	Treated	88	10·8	27·4	38·2*	28

* Total scale was estimated from the weight of solids supplied in the feed water, less the weight of solids removed in solution in the boiler water. Adherent scale was estimated by the difference.

The boilers were cleaned by hand but the fine sludge was difficult to collect and some may have been lost. It was not necessary to use acid to clean the boilers after this experiment.

Experiments 3, 4 and 5 (untreated water):—

During Experiment 3 suspended sludge was present in the water in both boilers. At the end of the test, sludge and scale were found in both boilers. There was more scale than sludge in Boiler A, and more sludge than scale in Boiler B. The scales in both boilers were thinner, smoother, and more firmly adherent than in Experiment 1.

At the end of Experiment 4 (which was a repetition of Experiment 3) the interior of Boiler A was covered with a rough granular scale, flaking over a considerable area, but there was no sludge. Boilers B and C contained a thin hard adherent layer of smooth scale and a considerable amount of sludge.

During Experiment 5 the water in Boiler A was clear but in Boilers B and C it contained suspended solids, and sludge was discharged during blowdown. At the end of the experiment the deposit in Boiler A was wholly in the form of scale which was thin, granular, and very loose, flaking away in fairly large pieces. The deposit in Boilers B and C was mainly in the form of sludge but there was also a thin smooth adherent layer of scale.

Experiments 6 and 7 (treated water):—

At the end of Experiment 6, most of the interior of the boilers was covered by a very thin, grey scale. On horizontal surfaces the scale was softer and whiter and might have been deposited first as sludge. This type of scale was fairly extensive in Boiler B. In all the boilers there was a deposit of sludge on the furnace crown, in the cross tubes, and in the base of the boiler.

During Experiment 7 the water in Boiler A contained solids in suspension, but there was no abnormal turbidity in the water in Boiler B. Both boilers were shut down for three days one week before the end of this experiment. When opened, the interior of both boilers was covered by a thin, fairly hard layer of scale. In Boiler A this was rough and composed of small crystals, and from its appearance it is considered possible that it included some material originally deposited as sludge. This effect was not seen in Boiler B, where the scale was granular and composed of larger crystals than in Boiler A. Some flaking had occurred in both boilers and there was a deposit of sludge in Boiler A but not in Boiler B. The usual method of cleaning the boilers with acid could not be used in this case, and the amount of total and adherent scale was estimated, by difference, from the total weight of solids supplied in the feed water, solids accounted for as easily removable scale, and solids present in the blowdown and boiler waters.

When the boilers were inspected at the end of each experiment, samples of deposits were collected and a selection of them was examined by the X-ray diffraction method. The only crystalline form of calcium carbonate which could be detected in the samples was calcite, and the only difference between scale and sludge was in the size of the crystals.

TABLE VII

Average Proportion of Loose Scale or Sludge in the Deposits in Boilers at an Airport

	PROPORTION OF DEPOSIT EASILY REMOVABLE (PERCENT)			
	Boiler A	Boiler B	Boiler C	All Boilers
Treated water	36	53	81	47
Untreated water	33	57	78	54
All waters	35	56	79	51
Difference between treated and untreated water	+3	—4	—3	—7

Conclusions from Group II Tests

The results of Group II tests show large variations in the nature of the deposits in the same experiment and in the same boiler in different experiments. Particulars of the estimated weight of calcium (as calcium carbonate) deposited as loose scale or sludge and as adherent scale, and the proportion of total deposit which was removed as loose scale or sludge in each boiler in the seven experiments are given in Table VI. Average values for the proportion of scale which was easily removable in the experiments with treated and with untreated water are summarized in Table VII. There were wide differences between the individual proportions in both groups, and there is no statistical significance in the difference between the average proportion of easily removable scale in boilers receiving treated and untreated waters. A similar conclusion is reached when the boilers are considered separately, although the average proportion of easily removable scale in individual boilers ranged from 35 percent in Boiler A to 79 percent in Boiler C.

Summary and Conclusions

Untreated hard water is often used as the make-up for low pressure boilers, and the hardness salts are deposited inside the boiler either as scale or sludge. Scale deposits are difficult and costly to remove and various processes have therefore been evolved with the object of causing the preferential formation of sludge instead of scale.

Two types of electrical equipment designed for this purpose have been tested jointly by the Fuel Research Station and the Water Pollution Research Laboratory of the Department of Scientific and Industrial Research. The tests were carried out partly on small experimental boilers made specially for the tests and partly on small commercial boilers operating under normal conditions.

During both groups of tests, marked differences were observed in the quantity and nature of the deposits. These differences do not appear to be associated in any way with the electrical treatment of the feed water, and they are equally apparent whether electrical treatment is used or not. Presumably, they are due to some other variable, the nature of which is not revealed by the tests applied. This variable is

elusive and to track it down would probably require a very long investigation.

Acknowledgments

The investigation described was made as part of the programs of the Fuel Research Board and the Water Pollution Research Board of the Department of Scientific and Industrial Research, and the paper is published by permission of the Directors of Fuel Research and of Water Pollution Research.

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G.P. 310,812; 340,785; 421,618; 440,979; 449,852; 459,-590; 533,781; 621,650; 669,610.
F.P. 813,953.
B.P. 410,914; 427,373; 429,564; 450,594; 450,628; 487,-595.
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CORRESPONDENCE*

Aquastat Ltd.,
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Tufton Street,
London, S.W.1.

The Secretary,
The Institution of Water Engineers,
Parliament Mansions,
Abbey Orchard Street, S.W.1. *28th July 1952.*

Dear Sir,

ELECTRICAL TREATMENT OF BOILER FEED WATERS

As the largest manufacturers of electrical water pre-treatment plant to prevent scale, we were a little disturbed to read the paper on this subject which appeared in your issue of November 1951 (vol. 5, p. 686), under the authorship of Messrs. T. F. Hurley, H. Ingleson, W. J. Sparkes, and R. Wilkinson.

The average reader could well infer that it is a report based on a complete series of experiments carried out by the Department of Scientific and Industrial Research addressed to testing electrical water treatment plant in accordance with the way in which manufacturers of such plant would recommend that the plant and the boilers should be operated. In the case of our particular apparatus, this is not the case, and we are sure that the authors would not like to convey such an impression. Thus, in the tests described by the authors, the boilers were not blown down until the total dissolved solids had reached a prescribed value, and subsequent blowing down was arranged to maintain the total dissolved solids at that figure.

We ourselves recommend that each feed water should be considered individually, and, in the case of the water supplied during the tests carried out at the airport, our recommendations would be that, from the time steam was first raised, the boiler should be given a small daily blow-down in short gulps with an interval between each gulp, if possible after the boiler had been quiescent for a while, so as to allow the sludge to settle at the bottom. By doing this, most of the solids would have been removed from the boiler before they had had a chance to burn on the heating surfaces.

Whilst these most interesting experiments do undoubtedly show what can happen inside boilers operated in the manner stated, they cannot be taken as any criterion of what would have happened if the boilers had been blown down in the way which we recommend.

It is much to be regretted that time did not permit the Department to make further experiments in which blow-down was carried out on the lines of our recommendations, for many years of experience have taught us that the results then would have been very different indeed.

We express our great appreciation of your courtesy in publishing this letter.

Yours faithfully,
"AQUASTAT" LIMITED,
A. G. Freeborn,
Managing Director.

Department of Scientific and Industrial Research,
Fuel Research Station,
Blackwell Lane, East Greenwich,
London, S.E.10.

The Editor,
Journal of the Institution of Water Engineers.

Dear Sir, *29th July 1952*

ELECTRICAL TREATMENT OF BOILER FEED WATERS

We have read with interest the letter you have received from Mr. A. G. Freeborn of Aquastat Limited about our paper published in the November 1951 issue of your *Journal*.

We agree with Mr. Freeborn that in all our tests we followed the practice of blowing down to prevent the concentration of total dissolved solids in the the water in the boiler exceeding a chosen value.

Our experiments were designed to test the effects of electrical treatment without otherwise varying the method of operation. If methods of blowing down different from those which we used during our tests are to be adopted, it would obviously be necessary to determine the effect of the change in the system of blow-down, apart from, and in addition to, the effect of electrical treatment. This would involve a further long series of experiments.

We do not claim that the results we obtained necessarily apply to conditions other than those of the tests we carried out as described in our paper. Nor do we claim that our series of tests, which had to be discontinued owing to the pressure of other work, covered all the possible variations in such factors as the composition of the boiler feed water, and the type and method of operation of the boilers.

Yours faithfully,

T. F. HURLEY, H. INGLESON,
W. J. SPARKS, R. WILKINSON.
Gwyn Hall, Neath, Glam.

* Reprinted from *J. Institution Water Eng.*, London, Vol. 7, 392-4 (1952) Oct.

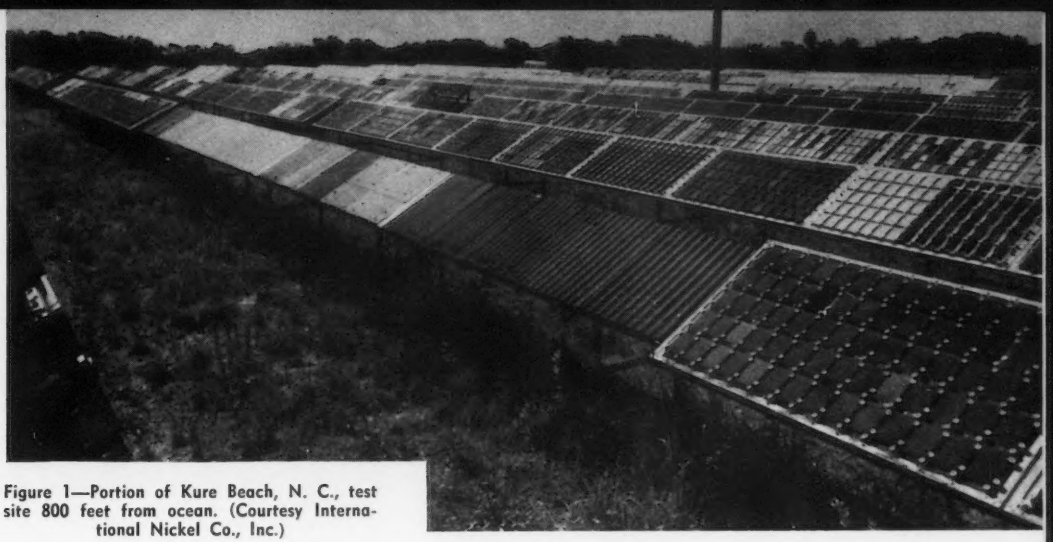

Figure 1—Portion of Kure Beach, N. C., test site 800 feet from ocean. (Courtesy International Nickel Co., Inc.)

Corrosion Resistance of High-Strength Low-Alloy Steels As Influenced by Composition and Environment*

By C. P. LARRABEE*

Introduction

SINCE the commercial introduction of steels designated by different manufacturers as high-strength low-alloy steel, high-tensile steel and high-tensile low-alloy steel, much has been written concerning the corrosion resistance of these materials.[1,2,3,4] As a group, these steels are characterized by a yield point about 1½ times that of structural carbon steel and many of them, some incorrectly, have been described by their manufacturers as having "four to six times the corrosion resistance of ordinary steels." In order that the many factors affecting corrosion resistance may be more thoroughly understood and also in order that more of the quantitative data available on this subject may be conveniently accessible, information on the comparative corrosion resistance of many of these materials in different natural media has been assembled and a discussion has been prepared to describe the limits within which such data are applicable.

The corrosion of steels is a function of both environment and composition. The environments herein considered are various atmospheres, natural waters, and soils. The compositions considered are mostly those of commercial steels, but those of a few experimental heats are also included.

★ Submitted for publication March 24, 1953.
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Abstract

The corrosion resistances of several high-strength low-alloy steels in various atmospheres, in natural waters and in soil are compared with those of structural copper steel and structural carbon steel in the same environments. The effects of the many variables that influence the corrosion of these steels in the different media are fully discussed. 41 References.

Atmospheric Corrosion

1. *Effect of Location*

A considerable amount of quantitative data has been published[2,3] from corrosion tests in industrial atmospheres, but extensive tests in marine atmospheres have been made only since 1940. At Kure Beach, North Carolina, is located what is probably the most extensive marine-atmosphere test site in the world, a portion of which is shown in Figure 1.

Data from tests in both industrial and marine atmospheres reveal that very great differences in corrosivity can exist at locations only a few miles apart, or—in some extreme cases—only a few hundred feet apart. In the industrial atmosphere at Altoona, Pennsylvania, for example, the average "years to first rust" of 18 sheets of galvanized steel having a coating of 1.25 oz/sq ft and of 18 sheets having a coating of 1.50 oz/sq ft was 2.4 and 3.0 years, respectively; whereas at State College, Pennsylvania (about 33 miles northeast), the comparable figures were 14.6 and 17.0 years.[5] The average num-

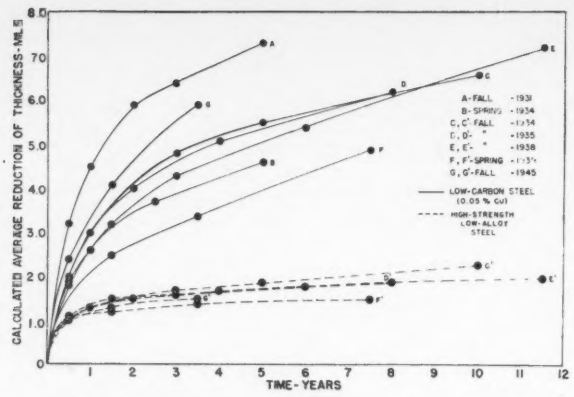

Figure 2—Time-Corrosion curves of two steels exposed to industrial atmosphere at Kearny, N. J. Effect of exposing steels in the atmosphere at various times. (Compositions in Table I.)

TABLE I

Compositions of Steels Exposed to the Industrial Atmosphere at Kearny, N. J. at Various Times—Percent

Indentification	C	Mn	P	S	Si	Cu	Ni	Cr
High-Strength Low-Alloy Steel.....	0.09	0.24	0.15	0.024	0.80	0.43	0.05	1.1
Low-Carbon Steel..	0.04	0.49	0.07	0.042	0.003	0.05	0.01	0.10

ber of years before a perforation was visible in duplicate uncoated sheets at the same two locations was 4.3 and 24.0 years, respectively.

LaQue[6] found even more striking differences in corrosion rates of test specimens at adjacent locations. He states that pieces of open-hearth iron (low-metalloid steel) at Kure Beach lost eight times as much weight when exposed about 80 feet from the ocean as when exposed at the nearby location shown in Figure 1, which is 800 feet from the ocean. The 80-foot location is over five times as corrosive to open-hearth iron as the most severely corrosive industrial atmosphere recorded in a cooperative survey of 18 locations throughout the world.[7] LaQue[6] also advises that after 11 months exposure in Texas, specimens of open-hearth iron at three locations—the first 12½ miles inland, the second on the shore of a bay and the third two miles inland from the second but in the center of a chemical plant—corroded in the ratios of 1:2:26, respectively.

The above examples illustrate the tremendous effect that local atmospheric contamination can have on corrosion rates and the large difference in corrosivity that may exist within a comparatively small area.

2. *Effect of Initial Climatic Conditions and of Method of Exposure*

Major differences have been reported[8] in the corrosion rates of steel specimens that were exposed at the same test site at successive two-month intervals. In addition, the time-corrosion curves of low-carbon steel specimens (0.05 percent copper) exposed at the same location are markedly different according to whether the original exposure was in the spring or fall of the same year or whether the original exposure was in the same season of different years (Figure 2). These differences are not so marked for the high-strength low-alloy steels. The compositions of the steels tested are given in Table I. The same low-carbon steel has been used in many other tests at Kearny, N. J., the results of which are not shown because the curves lie between the extremes of those shown in Figure 2.

It is probable that the weather conditions immediately after exposure greatly influence the atmospheric-corrosion rate of steel, as they influenced the corrosion of the zinc specimens reported by Ellis.[9] He states that for duplicate sets of specimens originally exposed within several days of one another, differences in the type of weather during the first few days of each exposure made a 100 percent difference in the respective amounts of corrosion that occurred during the following year.

In 1916, Sub-Committee III of Committee A-5, ASTM, decided to test uncoated steel sheets at an angle of 30 degrees to the horizontal and facing south. With the exception of paint tests, this proce-

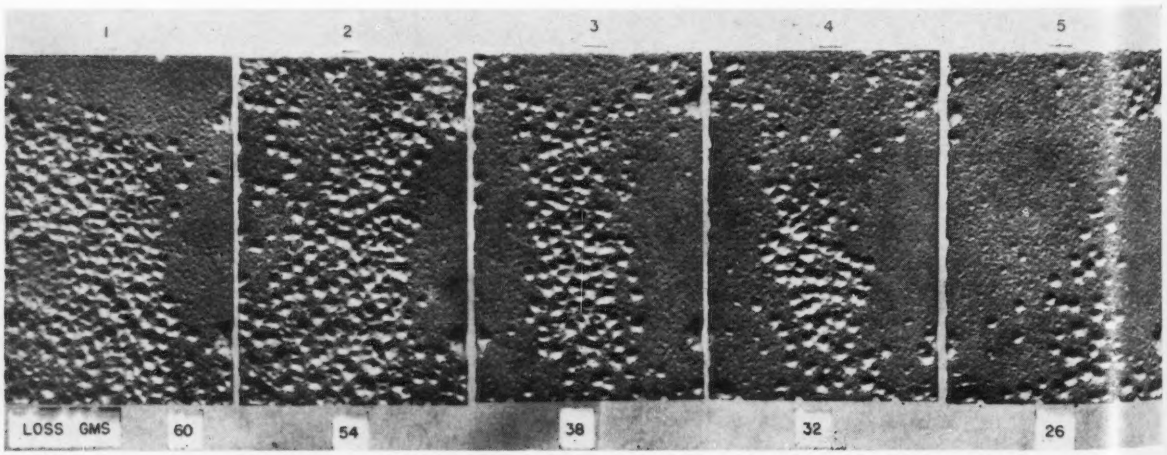

Figure 3—Cleaned groundward surfaces of five 4 x 6-inch specimens of structural carbon steel which had been exposed one above another on a 30 degree rack in a marine atmosphere. No. 1 was uppermost.

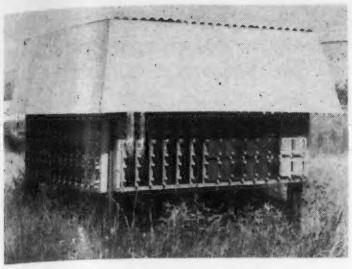

Figure 4—Shelter test rack.

dure has been followed for most exposure tests in this country. Vertical exposures of test specimens are used by the Corrosion Committee of the British Iron and Steel Federation[10] in their field tests, which were initiated about 1931.

Taylerson reports[11] that vertically exposed specimens lost weight somewhat faster than do those exposed at 30 degrees to the horizontal. LaQue[6] states that the reproducibility of results is poorer when the specimens are exposed vertically than when the specimens are exposed at 30 degrees to the horizontal. This may be caused by the fact that a slight variation in the position of the specimen from the vertical results in a slight sheltering of one surface of the specimen and reduces the amount of washing which that surface receives from rain. The importance of this sheltering effect should not be underestimated. It has been shown[12] that for steel specimens exposed at 30 degrees to the horizontal in industrial and semi-rural atmospheres, the ratio of the losses of weight of the skyward and groundward surfaces was about 38 to 62. The smaller loss on the skyward surface was attributed to the removal of corrosive sulfur compounds from the rust by the washing action of rain and dew.

This ratio may vary considerably according to the exact conditions encountered. In Figure 3 are shown the cleaned groundward surfaces of five specimens of structural steel (0.02 percent Cu) after two years exposure one above another on a 30 degree rack facing south in a marine atmosphere. It is evident from the number of pits that the amount of sea spray from the east that was deposited on the groundward side of the specimens increased with the height of the specimens above the ground. Only steels with low residual-copper content have shown this phenomenon. Corrosion of the skyward surfaces was relatively mild and uniform because sea spray deposited on the skyward surface was washed off by rain. To obtain more information on the effect of sheltering, test specimens were mounted vertically in perpendicular rows of five specimens each as shown in Figure 4. The upper two specimens were fully sheltered from rain. In 1944, specimens were exposed facing north, east, south and west at a semi-rural test site near South Bend, Pa., and on the lot 800 feet from the ocean at Kure Beach.

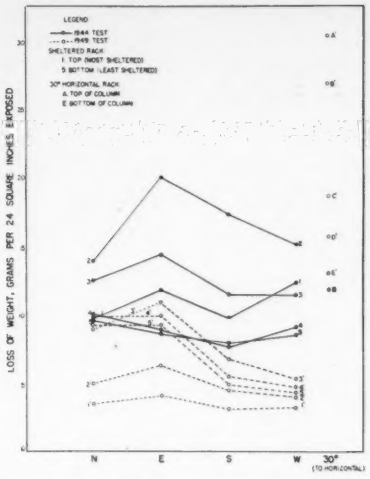

Figure 5—Effect of amount of shelter and direction of exposure on corrosion of carbon steel after exposures in marine atmosphere for two years.

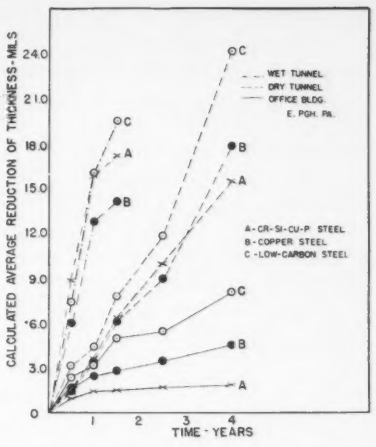

Figure 6—Time-corrosion curve. Specimens exposed in tunnels and industrial atmosphere. (Compositions in Table II.)

TABLE II
Compositions of Steels Exposed in Railroad Tunnels and in Industrial Atmosphere—Percent

Indentification	C	Mn	P	S	Si	Cu	Ni	Cr
A*.....	0.11	0.39	0.13	0.023	0.66	0.36	0.08	1.0
B.....	0.04	0.31	0.011	0.014	0.002	0.24	0.01	0.03
C.....	0.03	0.19	0.003	0.011	0.003	0.024	0.03	0.02

* A High-Strength Low-Alloy Steel.

Examination of specimens removed after four years' exposure at the semi-rural test site showed that there were only relatively small weight-loss variations that could be attributed to the differences in amount of shelter and direction of exposure. Similar effects were shown by each type of steel exposed—low-carbon steel, copper steel and a high-strength low-alloy steel of the Cr-Si-Cu-P type. The results are summarized in the following table.

Results at Semi-Rural Test Site

Direction of Exposure	Effect of Shelter
East	Practically no effect of shelter.
North	The two bottom specimens were about 20 percent *more* corroded than those in the other three positions.
South or West	The two bottom specimens were about 20 percent *less* corroded than those in the other three positions.

The two bottom specimens facing south or west received more sunlight than did those facing north; this greater amount of sunlight must have resulted in a more protective rust film on the former. The specimens that were exposed southward in this vertical rack had from 50 to 100 percent higher corrosion losses than duplicate specimens that were exposed southward at 30 degrees to the horizontal on regular test racks.

In the marine atmosphere at Kure Beach the re-

sults were very different. The results of this test are summarized in the following table.

Results at Marine-Atmosphere Test Site

Direction of Exposure	Effect of Shelter
East	The specimen located in position two (next to the top specimen in vertical row) lost from 150 to 250 percent more weight than the specimens in positions four and five, or the specimen at 30 degrees to the horizontal. The top specimen, and that in the third position, lost from 50 to 100 percent more weight than those in positions four and five.
North or South	The specimen in position two lost about 75 percent more weight than those in positions four and five.
West	All losses were within ± 30 percent of average for all five vertical positions.

This extreme variation is believed to have been caused by more sea water having been deposited on the specimens facing east (toward the ocean) by hurricane-force winds during the first few months of exposure than was deposited on the specimens facing north or south. The specimens facing west received the least sea-water spray. The losses on the two bottom specimens were lowest because the salt was washed from the rust by rain.

Data from a similar test begun at the same site in 1949 do not show such extreme variations; moreover, the losses of the sheltered specimens are less than the average loss of the five vertically exposed specimens. The losses of the five specimens exposed at 30 degrees to the horizontal (photographs in Figure 3) are greater than any of those of the five vertically exposed specimens. As in the test described above, this is probably because the sea-water spray on the groundward sides of the former greatly accelerated the attack. The 1944 and 1949 tests results summarized in Figure 5, illustrate the very great differences that can be caused by changes in climatic conditions even at the same test site.

3. *Effect of Continuously Moist Conditions*

A) **On steels exposed in tunnels**

In the previously described shelter tests the high-strength low-alloy steel consistently lost less weight than either the low-carbon steel or the copper steel, probably because the rust films of all specimens periodically became dry. For when these three steels remain continuously moist, especially with water of low pH, the superior resistance exhibited by the high-strength low-alloy steels in open exposures is not observed.

For example, tests were made of a low-carbon steel, a copper steel and a high-strength low-alloy steel in one railroad tunnel with continuously wet walls, in a second tunnel with dry walls and on the roof of an office building in an industrial district. The compositions of the steels are given in Table II. The rust films formed in the wet tunnel were apparently not so protective as those formed during a similar period of time on steels fully exposed to the atmosphere. Consequently, as seen in Figure 6, the corrosion rates of the three steels in the wet tunnel are nearly linear and exhibit little tendency to decrease as do the rates of the steels on the top of the building. Furthermore, the high-strength low-alloy steel does not show so great a superiority in corrosion resistance over that of copper steel and low-carbon steel when exposed in the tunnels as when fully exposed to the out-door atmosphere (roof of building); in fact, the copper steel lost less weight in the wet tunnel than did the high-strength low-alloy steel. The atmosphere in the wet tunnel was so severely corrosive that after one year of exposure,

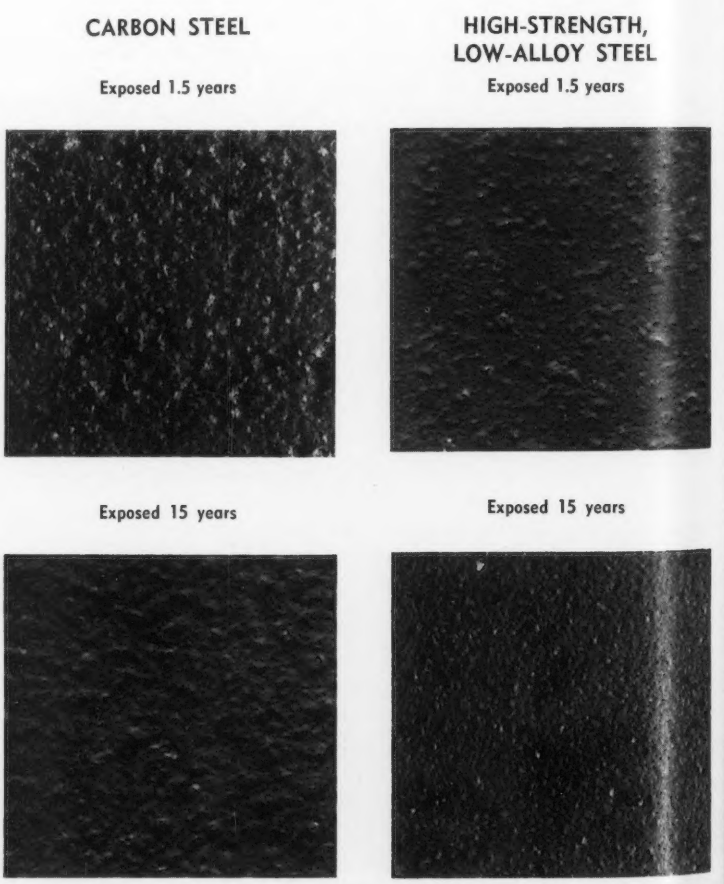

Figure 7—Actual size photographs of rusts on carbon steel (left) and on high-strength low-alloy steel (right) after 1.5 and 15 years' exposure to industrial atmosphere.

the loss of weight of the high-strength low-alloy steel was more than 11 times that of the same steel exposed on the roof.

B) **On steels used as roofing sheets**

Studies have also been made of the effect of continuously moist conditions on the corrosion of several roofs made of uncoated corrugated sheets of high-strength low-alloy steel, of copper steel and of carbon steel. After several years service the faying surfaces of many of these sheets had been corroded so much that little or no metal remained; the accelerated attack is ascribed by the author to condensation draining down the inside of the roof into the lapped joints at the ends and sides of the sheets. Laps of roofing sheets, therefore, should be well protected by suitable paints. Corrosion at these areas is particularly severe in many industrial buildings because the condensation on the inside of the roofs sometimes contains sulfur fumes, which will rapidly corrode faying surfaces that remain wet a large percentage of the time. The rust films formed under such conditions are not nearly so protective as those formed on areas fully exposed to the atmosphere.

A detailed discussion of the preparation of the steel surface and the properties of various paints is beyond the scope of this paper. However, it is pertinent to this discussion to mention the fact that the life of a paint system on steel depends on the corrosion resistance of the steel. Most paints are somewhat permeable to moisture and if the resultant rust is sufficiently voluminous, the paint film will be blistered and finally broken. The nature of the rust film that forms on the steels is, therefore, important to the life of a paint film, especially at areas such as faying surfaces where repainting cannot be done. The rust formed on carbon steel during the first months of exposure is much more voluminous than the rust formed on high-strength low-alloy steel under similar conditions (Figure 7). It is of interest to note that upon much longer exposures of similar unpainted steels, the differences in appearance are not so great because the loose rust particles have been removed by action of wind and rain.

4. *Effect of Composition of Steel*

It is important to know the fundamental reasons why certain steels exhibit superior atmospheric-corrosion resistance, because the differences in this resistance are often of such magnitude that the more resistant steels have important advantages. Since the pioneering work of Buck[13] and the early publication[14] and interpretation[15] of the results of the ASTM tests, it has been generally acknowledged that carbon steel containing 0.2 percent or more copper has from 1½ to 4 times the atmospheric-corrosion resistance of a similar steel containing only 0.01 to 0.02 percent residual copper. The greatest differences in corrosion rates are found in the more severe industrial and marine atmospheres and the smallest differences are found in moderate marine and rural atmospheres. Since the development of the high-strength low-alloy steels in the early 1930's, the superior atmospheric-corrosion resistance of these steels over that of copper steel has been extensively demonstrated.[3, 16, 17, 18, 19, 20]

Only a little experimental work has been done in investigating the fundamental reasons underlying this observed superiority in atmospheric-corrosion resistance. However, extensive field tests indicate a close relation between the corrosion resistance and the composition of a given steel. Buck[13] ascribed the superiority in corrosion resistance of copper steels over low-residual-copper steels to the presence of copper sulfide rather than ferrous sulfide in the steel, and Buck's theory has been substantiated by the writer. Four low-metalloid irons having various sulfur and copper contents, as shown below were exposed in an industrial atmosphere.

Iron	Per Cent S	Per Cent Cu
A	0.000	0.000
B	0.000	0.2
C	0.03	0.2
D	0.03	0.01

It was found that irons A, B and C lost nearly equal amounts of weight, whereas the loss of D (with more sulfur than copper) was measurably greater. Thus, it is evident that the presence of copper is of importance to the atmospheric-corrosion resistance of iron only if sulfur is present.

Copson[21] ascribes the superiority in corrosion resistance of high-strength low-alloy steels over copper steels to the clogging of the pores of the rust films in the former with such corrosion products as chro-

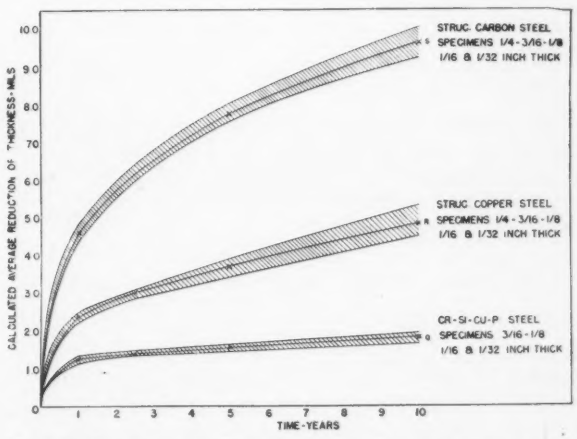
CALCULATED AVERAGE REDUCTION OF THICKNESS-MILS
TIME-YEARS
STRUC. CARBON STEEL
SPECIMENS 1/4 - 3/16 - 1/8
1/16 & 1/32 INCH THICK
STRUC. COPPER STEEL
SPECIMENS 1/4 - 3/16 - 1/8
1/16 & 1/32 INCH THICK
CR-SI-CU-P STEEL
SPECIMENS 3/16 - 1/8
1/16 & 1/32 INCH THICK

Figure 8—Comparative corrosion of steels of varying thicknesses. Industrial atmosphere, Kearny, N. J. Shaded areas on both sides of "average curve" show range of losses of the specimens. (Compositions in Table III.)

TABLE III
Compositions of Steels of Various Thicknesses in Test in Industrial Atmosphere at Kearny, N. J.—Percent

Indentification	C	Mn	P	S	Si	Cu	Ni	Cr
Q*	0.09	0.30	0.16	0.035	0.93	0.42	0.03	1.1
R	0.18	0.49	0.024	0.034	0.025	0.32	0.02	0.02
S	0.17	0.57	0.019	0.05	0.043	0.05	0.02	0.02

* A High-Strength Low-Alloy Steel.

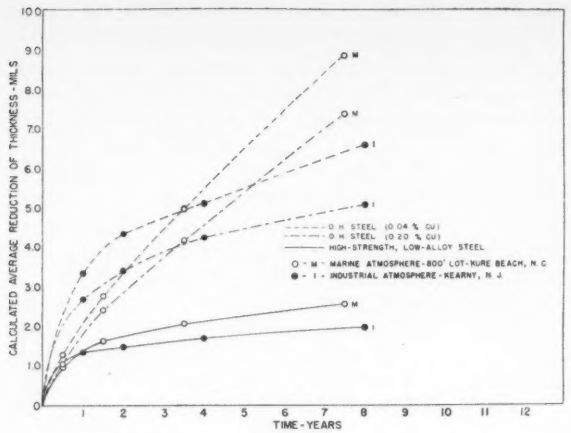
CALCULATED AVERAGE REDUCTION OF THICKNESS - MILS
TIME - YEARS
O.H. STEEL (0.04 % CU)
O.H. STEEL (0.20 % CU)
HIGH-STRENGTH, LOW-ALLOY STEEL
O - M - MARINE ATMOSPHERE - 800' LOT - KURE BEACH, N. C.
● - I - INDUSTRIAL ATMOSPHERE - KEARNY, N. J.

Figure 9—Time-corrosion curves of three steels in marine and industrial atmospheres.

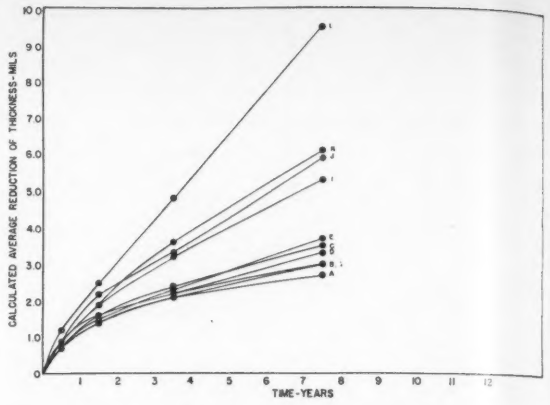

Figure 11—Time-corrosion curves of steels in marine atmosphere at Kure Beach, N. C. Exposed Dec. 13, 1940. L and K are carbon and copper structural steels, respectively. Others are high-strength, low-alloy steels. (Compositions in Table IV.)

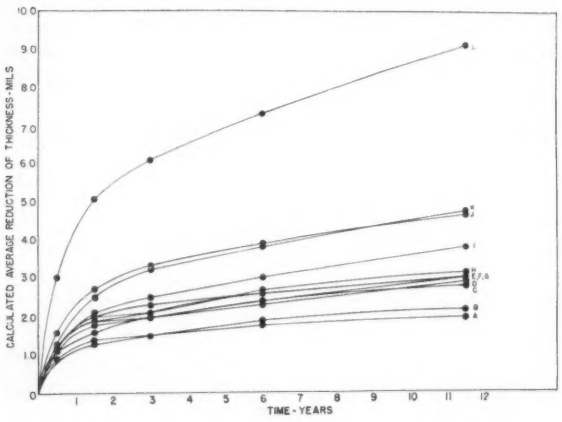

Figure 10—Time-corrosion curves for steels in industrial atmosphere, Kearny, N. J. Exposed Oct. 14, 1938. L and K are carbon and copper structural steels, respectively. Others are high-strength, low-alloy steels. (Compositions in Table IV.)

mium sulfate and nickel sulfate, both of which are more insoluble than iron sulfate. This clogging tends to prevent water from reaching the surface of the metal. Copson further states that this may not be the complete explanation, since it does not explain the improvement in atmospheric-corrosion resistance that is realized when the steels contain greater than residual amounts of phosphorus and silicon. This improvement is especially marked when the steel contains 0.1 percent or more copper.

More satisfactory explanations must await further study of rust films. Differences in the appearance of the rust films on copper steels and steels with low residual-copper contents have been noted by many, including Committee A-5 of the ASTM.[22]

It is probably the nature of the rust film immediately adjacent to the metal that determines how protective it will be and, hence, the subsequent corrosion rate of the steel. The problem of studying this extremely thin film by itself, however, is complicated by the difficulty of isolating it from the remainder of the rust film.

The nature of the rust film depends on the environment in which the steel is exposed and the composition of the steel and is independent of the thickness of the steel. This was shown in a series of tests in which specimens of different thicknesses from three grades of steel were exposed simultaneously to the atmosphere at Kearny, New Jersey. The losses of weight were determined after various periods of exposure up to ten years. The average reductions in thickness calculated from the losses of weight are shown in Figure 8. The shaded areas indicate the range of individual losses for each grade of steel. The compositions are given in Table III. It will be

TABLE IV

Compositions of Steels Exposed at Kearny, N. J., and Kure Beach, N. C.—Percent
(See Figures 10 and 11)

Identification	EXPOSED AT[1]		C	Mn	P	S	Si	Cu	Ni	Cr	Mo
	Kearny	Kure Beach									
A*	8	..	0.09	0.29	0.14	0.023	0.74	0.39	0.05	0.99	....
A*	..	2	0.08	0.28	0.13	0.024	0.75	0.39	0.06	0.96	....
B*	5	..	0.13	0.48	0.10	0.025	0.008	0.69	1.5	0.11	0.12
B*	..	2	0.14	0.47	0.10	0.023	0.007	0.71	1.5	0.15	0.10
C*	2	2	0.08	0.90	0.009	0.016	0.02	1.5	1.0	0.03	0.09
D*	1	1	0.08	0.49	0.11	0.020	0.14	0.95	0.57	0.01	....
E*	3	..	0.09	0.40	0.10	0.021	0.064	0.55	0.64	0.04	0.10
E*	..	1	0.08	0.39	0.09	0.012	0.09	0.55	0.71	0.03	0.12
F*	3	..	0.06	0.37	0.02	0.018	0.054	1.01	2.0	0.01	....
G*	2	..	0.19	0.65	0.022	0.020	0.88	0.23	0.11	0.65	....
G*	..	1	0.23	0.59	0.023	0.018	0.85	0.24	0.11	0.73	....
H*	1	..	0.09	0.56	0.08	0.027	0.06	0.52	0.30	0.31	....
I*	3	..	0.11	0.52	0.08	0.027	0.004	0.40	0.10	0.05	....
I*	..	2	0.12	0.52	0.08	0.027	0.004	0.40	0.09	0.05	....
J*	2	..	0.20	1.0	0.012	0.028	0.24	0.21	0.05	0.03	....
J*	..	1	0.19	1.0	0.010	0.027	0.24	0.21	0.05	0.03	....
K†	2	..	0.25	0.48	0.019	0.038	0.020	0.24	0.01	0.08	....
K†	..	1	0.27	0.48	0.024	0.036	0.009	0.21	0.01	0.12	....
L†	2	..	0.21	0.53	0.016	0.034	0.023	0.025	0.01	0.03	....
L†	..	2	0.23	0.53	0.023	0.044	0.026	0.039	0.02	0.07	....

[1] Numerals in these columns show the number of different heats of steel used to represent that particular type. In all cases the differences in compositions between steels in any one group are negligible.

* High-Strength Low-Alloy Steels.

† Structural Copper and Structural Carbon Steels.

noted in Figure 8 that the deviation of any one specimen from the mean value for each material is relatively small; any possible effect of specimen thickness is negligible compared to the effect of composition.

On many steels, the rust film developed during the first few years of exposure in an industrial atmosphere is more protective than the film developed in a marine atmosphere. This is illustrated by a comparison of the time-corrosion curves in Figure 9. The corrosion rates for all three materials in the industrial atmosphere decrease markedly after an exposure of one to two years, as shown by the flatness of their time-corrosion curves (Figures 8 and 9), whereas the formation of rust has less effect on the corrosion rates of carbon steel and even of copper steel in the marine atmosphere (Figure 9). The rust on the high-strength low-alloy steel, however, markedly decreases the rate of corrosion in the marine atmosphere but not to the same extent as in the industrial atmosphere.

The atmospheric-corrosion resistances of a group of steels exposed simultaneously at one location depend on the compositions of the steels. Time-corrosion curves covering many steels for exposure periods of six years in an industrial atmosphere have been published.[3] Additional data obtained after exposures of 11½ years are in accordance with the corrosion rates established by the 3-year and the 6-year exposures (Figure 10. Compositions in Table IV). From these data the effect of steel composition on corrosion rates is evident. Many of these same commercial steels have been tested in marine atmospheres and the results are given in Figure 11 (compositions in Table IV).

The high-strength low-alloy steels included in these early tests (Figures 10 and 11) were produced in 1938. Since then, similar types of steel of other compositions have been developed. Their rates of corrosion, which may be compared with those of some of the materials used in the early tests, are shown in Figures 12 and 13. The compositions of some of these products, given in Table V, show them to be similar to those in Table IV with the same letter identification. From Figures 8 to 13, it is evident that in general, the slope (corrosion rate at any one time) of the time-corrosion curve for a given atmosphere after about 3.5 years is a function of the loss at 3.5 years—the greater the loss, the steeper the slope. Thus, the longer the exposure, the greater will be the difference in the amounts of corrosion of the various steels. This is also illustrated by Figure 14. The negligible corrosion rate of the high-strength low-alloy steel subsequent to an exposure of one year in the severe industrial atmosphere at Kearny is well illustrated by calculations made from the data in Figure 14: For the period between 1 and 16 years, the total decrease in thickness of this material was only 0.0008 inch (calculated from losses of weight).

In Figure 15 are shown the losses in thickness of six commercial steels after 3.5 years of exposure at each of four locations having different types of

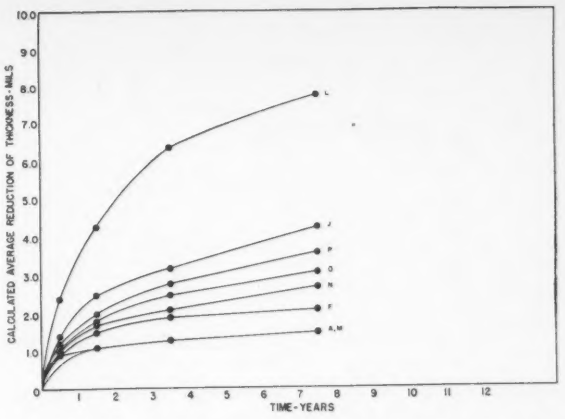

Figure 12—Time-corrosion curves of steels in industrial atmosphere at Kearny, N. J. Exposed Oct. 29, 1942. J and L are copper and carbon structural steels, respectively. Others are high-strength, low-alloy steels. (Compositions in Table V.)

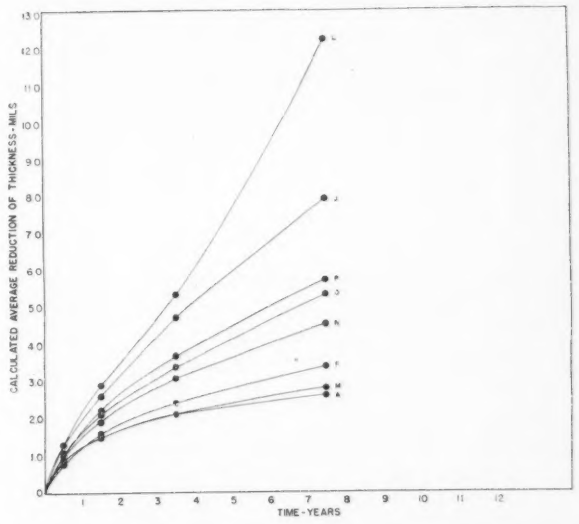

Figure 13—Time-corrosion curves of steels in marine atmosphere at Kure Beach, N. C. Exposed Nov. 14, 1942. J and L are copper and carbon structural steels, respectively. Others are high-strength, low-alloy steels. (Compositions in Table V.)

TABLE V

Compositions of Steels Exposed at Kearny and Kure Beach—Percent (See Figures 12 and 13)

Indentification	C	Mn	P	S	Si	Cu	Ni	Cr
A*.....	0.09	0.24	0.15	0.024	0.80	0.43	0.05	1.1
M*.....	0.06	0.48	0.11	0.030	0.54	0.41	0.51	1.0
F*.....	0.05	0.36	0.05	0.016	0.008	1.1	2.0	0.01
N*.....	0.11	0.55	0.08	0.026	0.06	0.55	0.28	0.31
O*.....	0.16	1.4	0.013	0.021	0.18	0.30	0.50	0.03
P*.....	0.23	1.5	0.018	0.021	0.19	0.29	0.04	0.08
J†.....	0.19	0.52	0.008	0.039	0.01	0.29	0.05	0.05
L†.....	0.16	0.42	0.013	0.021	0.01	0.02	0.02	0.01

* High-Strength Low Alloy Steels.
† Structural Carbon and Structural Copper Steels.

atmospheres. The most resistant steel (Cor-Ten brand steel) lost about twice as much at the most corrosive location as at the least corrosive. Structural carbon steel, however, lost about four times as much in the marine or the industrial atmosphere as at the rural locations. Some of these steels were more

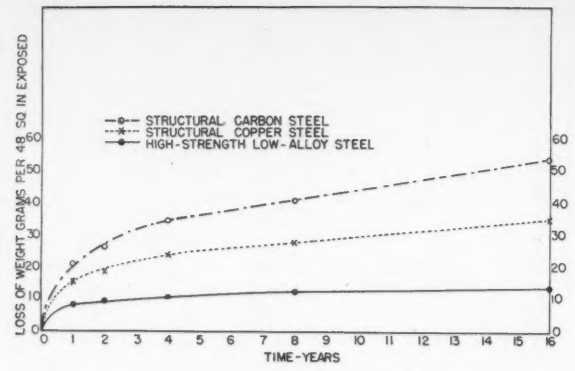

Figure 14—Time-corrosion curves of three steels in industrial atmosphere, Kearny, N. J.

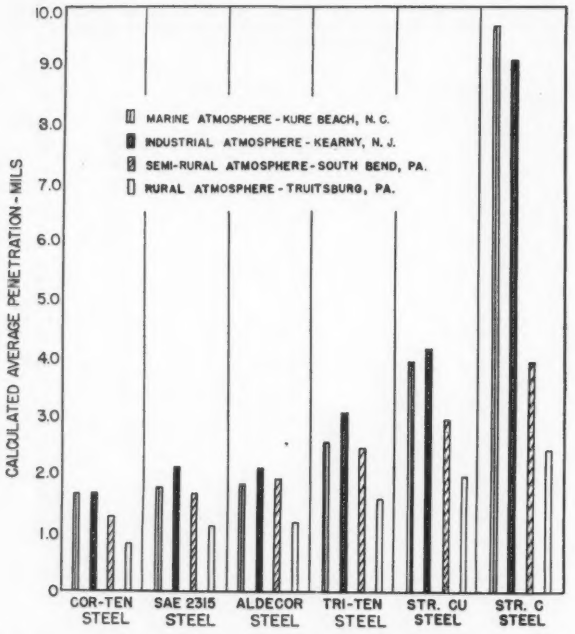
MARINE ATMOSPHERE - KURE BEACH, N. C.
INDUSTRIAL ATMOSPHERE - KEARNY, N. J.
SEMI-RURAL ATMOSPHERE - SOUTH BEND, PA.
RURAL ATMOSPHERE - TRUITSBURG, PA.
CALCULATED AVERAGE PENETRATION - MILS
COR-TEN STEEL
SAE 2315 STEEL
ALDECOR STEEL
TRI-TEN STEEL
STR. CU STEEL
STR. C STEEL

Figure 15—Comparative corrosion of six steels in four atmospheres, 3.5 years' exposure. (Compositions in Table VI.)

TABLE VI

Compositions of Steels Exposed in Marine, Industrial Semi-Rural, and Rural Atmospheres—Percent

Steel Material	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
Cor-Ten Brand	0.08	0.49	0.09	0.028	0.63	0.44	0.46	0.92	....
SAE 2315	0.19	0.53	0.016	0.022	0.01	0.07	3.2	0.09	....
Aldecor	0.09	0.31	0.11	0.029	0.57	0.48	0.04	0.03	0.23
Tri-Ten Brand	0.17	1.2	0.003	0.024	0.18	0.29	0.59	0.04	....
Structural Copper	0.20	0.46	0.005	0.034	0.003	0.25	....	0.04	....
Structural Carbon	0.23	0.40	0.005	0.017	0.003	0.020	0.04	0.03	....

resistant to the marine than to the industrial atmosphere, while with others the opposite was true.

As shown in Figures 11 and 13, the corrosion rates of the structural carbon steels will probably increase upon longer exposure in marine atmospheres. The increase in corrosion rates of this class of material

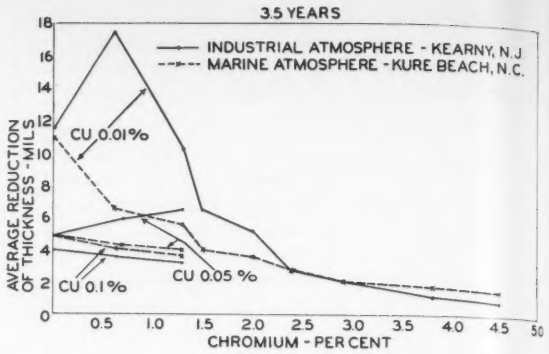

Figure 16—Atmospheric corrosion. Effect of increasing chromium, 3.5 years.

(material having low-residual alloying elements, including copper) is the only instance that has been noted of an increase in corrosion rates with time. As previously mentioned, it is probably caused by the accumulation of sea salt on the groundward side of the specimens.

Voluminous data could be presented concerning the effect of small amounts of copper, phosphorus and other alloying elements on the atmospheric-corrosion resistance of steel but one example (presented in Figure 16) will suffice for the present purposes. In the industrial atmosphere, the losses of weight of steels containing 0.01 percent and 0.05 percent copper increase with increasing chromium content up to 0.7 percent chromium, whereas in the marine atmosphere the presence of this amount of chromium results in a decrease in the losses of weight. This behavior remains unexplained. When 0.1 percent or more of copper is present in the steels, this peculiar effect of chromium is not evident.

Experimental results such as these have led to the accepted procedure of determining the corrosion resistance of each type of steel by actual long-time exposure tests in various atmospheres. Statements concerning the atmospheric-corrosion resistance of steels should be confined to comparisons based upon data obtained from simultaneous exposures of all the steels involved and the conditions of the exposures should be specified.

Corrosion by Waters

As discussed by Evans and Uhlig[23] and by others,[24] the corrosion of steel in waters is influenced by many factors such as the presence in the water of dissolved gases or metals, chlorides or sulfates, or organic matter with or without bacterial action. It is also influenced by the acidity or alkalinity, hardness, temperature, or rate of flow of the water; by the nature of corrosion products; by stray currents; by galvanic action; by presence of mill scale on the steel and by the composition of the steel. In many natural waters the corrosion of steels is a direct function of the oxygen content of the water.

It is not the purpose of this paper to discuss each of the above factors, but all have a bearing on the

amount and type (general or pitting) of attack. In natural waters the combined effect of all factors can be determined only by a time-consuming test. Such a test is necessary to accumulate reliable data for use in forecasting results of service installations.

It has been stated by LaQue[2] and also by Hudson[25] that significant improvement in the corrosion resistance of submerged steels is more likely to result from chromium than from most of the other commonly used alloying elements in steels. Substantiating data will be discussed later.

1. *Fresh Waters*

A summary of the results of immersion tests made in the Monongahela, the Allegheny and the Mississippi Rivers with the cooperation of the Department of the Army, Corps of Engineers, is given in Table VII; compositions of the materials tested are shown in Table VIII. Six grades of steel were used in these tests. The data show that in each river the average corrosion rates decrease with time. The Monongahela River water has a pH of 3.5 to 4.0, which explains the high rates of attack. The contaminant is largely ferric sulfate, which comes from coal-mine drainage.

Whether the superiority shown by Cor-Ten high-strength low-alloy steel in this river is of commercial significance is being determined by a comparison of the service life and maintenance costs of three coal barges made of Cor-Ten steel, and of similar barges made of structural copper steel. The superior resistance of this same high-strength low-alloy steel in the water found in one coal mine has been reported previously;[47] however, when the concentration of ferric sulfate was as high as occurs in some mines during periods of low rainfall, the corrosion of even this material was observed to be severe.

In the Allegheny River the corrosion losses of the various steels were not so dependent on composition as they were in the Monongahela. The decrease in average corrosion rate with time, while not so marked as in the Monongahela River, is still significant. The maximum depth of pits (measured with a pit-depth gage on the corroded surfaces) is nearly twice as great in the Allegheny as in the Monongahela River, possibly because the lower degree of turbulence of the former was more conducive to the formation of oxygen-concentration cells.

In the Mississippi River, specimens were immersed in a compartment of a dam where the water was nearly stagnant. The low oxygen content of the water is responsible for the much lower average corrosion rate here than in the other two rivers. This was shown by a 1.5-year test in which three specimens of Cor-Ten steel and three of structural carbon steel were exposed in the compartment as well as in nearby free-flowing water. The rates in the free-flowing water were about twice those in the com-

TABLE VII

Corrosion of Steels in River Waters
Corrosion Rates and Pit-Depth Data

STEEL	1-Year Exposure		2-Year Exposure		4-Year Exposure	
	Average Mils/Yr.	Max. Pit Mils	Average Mils/Yr.	Max. Pit Mils	Average Mils/Yr.	Max. Pit Mils
Monongahela River—Charleroi, Pa.						
Cor-Ten Brand[1]	4.9	8	3.1	12	2.7	14
Tri-Ten Brand[2]	7.0	13	4.6	18	4.0	21
Man-Ten Brand[2]	6.6	16	3.8	19	3.0	17
Structural Silicon[2]	6.4	13	5.2	20	3.5	31
Structural Copper[1]	6.4	12	4.1	19	3.5	29
Structural Carbon[1]	6.5	23	4.6	28	4.1	21
Allegheny River—Kittanning, Pa.						
Cor-Ten Brand[1]	3.5	23	3.5	37	2.4	35
Tri-Ten Brand[2]	3.8	42	3.6	35	2.6	32
Man-Ten Brand[2]	4.0	29	3.5	42	3.0	48
Structural Silicon[2]	4.2	23	3.7	38	2.9	41
Structural Copper[1]	4.2	24	3.6	31	2.5	34
Structural Carbon[1]	4.2	26	3.7	37	2.8	59
Mississippi River—Winfield, Mo.						
Cor-Ten Brand[1]	1.4	6	1.2	13	1.0	30
Tri-Ten Brand[2]	1.6	11	1.4	17	1.2	28
Man-Ten Brand[2]	1.5	12	1.3	14	1.1	25
Structural Silicon[2]	1.6	8	1.4	13	1.1	17
Structural Copper[1]	1.5	10	1.3	10	1.0	19
Structural Carbon	1.5	11	1.4	14	1.1	31

[1] Corrosion rates averaged from results of exposure of a foot-square specimen from each of three heats. Maximum pit is that found by examination of 6 square feet of surface.

[2] Corrosion rates averaged from results of exposure of a foot-square specimen from each of two heats. Maximum pit is that found by examination of 4 square feet of surface.

[3] Specimens placed in the nearly stagnant water in a compartment of a dam. Specimens of Cor-Ten steel and structural carbon steel corroded at twice the rates given herein when the exposure was in the open river.

TABLE VIII

Typical Compositions of Steels in Tests in Three Rivers

Identification	Steel	PERCENT							
		C	Mn	P	S	Si	Cu	Ni	Cr
1	Cor-Ten Brand	0.08	0.34	0.10	0.026	0.45	0.37	0.53	0.88
2	Tri-Ten Brand	0.19	0.92	0.015	0.028	0.18	0.36	0.90	0.05
3	Man-Ten Brand	0.21	1.37	0.021	0.024	0.21	0.28	.....	.....
4	Structural Silicon	0.39	0.78	0.011	0.028	0.22	0.042	0.03	0.02
5	Structural Copper	0.20	0.45	0.017	0.026	0.046	0.34	0.11	0.06
6	Structural Carbon	0.19	0.40	0.009	0.034	0.032	0.028	0.018	0.035

TABLE IX

Corrosion Rates of Steels in Sea Water

STEEL	Average Penetration, Mils per Year—Each Surface Years Exposure		
	1.5	2.5	4.5
Cor-Ten Brand	4.2	4.3	3.8
Tri-Ten Brand	4.4	3.8	3.0
Ni-Cu	5.3	4.5	3.5
Cr-Mo	1.4	1.6	1.6
Structural Carbon	4.8	4.1	3.3

STEEL	COMPOSITIONS—PERCENT								
	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
Cor-Ten Brand	0.08	0.36	0.08	0.026	0.31	0.41	0.49	0.73	....
Tri-Ten Brand	0.17	1.2	0.026	0.025	0.18	0.31	0.53	0.07	....
Ni-Cu	0.19	0.44	0.030	0.032	0.025	0.81	1.8	0.22	....
Cr-Mo	0.07	0.39	0.014	0.020	0.09	0.020	0.04	2.6	0.52
Structural Carbon	0.25	0.42	0.020	0.032	0.025	0.012	0.02	0.06	....

TABLE X

Results of Corrosion Tests in Panama Canal Zone[1]

Average Corrosion Rates Calculated From Losses of Weight and Deepest Pit as Measured by Pit-Depth Gage

DESIGNATION	SEA WATER Mean Tide						BRACKISH WATER Continuous Immersion						FRESH WATER Continuous Immersion					
	Corrosion Rate, Mils per Year			Deepest Pit, Mils			Corrosion Rate, Mils per Year			Deepest Pit, Mils			Corrosion Rate, Mils per Year			Deepest Pit, Mils		
	1 Yr.	3 Yrs.	5 Yrs.	1 Yr.	3 Yrs.	5 Yrs.	1 Yr.	3 Yrs.	5 Yrs.	1 Yr.	3 Yrs.	5 Yrs.	1 Yr.	3 Yrs.	5 Yrs.	1 Yr.	3 Yrs.	5 Yrs.
H-S L-A Steel A*	14	10	5	45	67	144	11	8	M	51	93	M	6	4	3	38	54	60
H-S L-A Steel B*	13	8	5	33	105	101	11	9	7	61	122	138	6	4	3	30	62	100
H-S L-A Steel C*	15	10	6	53	119	60	12	13	M	58	132	M	6	4	4	38	60	78
H-S L-A Steel D*	15	11	6	43	114	77	11	11	8	33	111	68	7	4	3	28	59	68
H-S L-A Steel E*	15	11	6	39	115	81	11	14	M	33	124	M	7	5	3	23	55	81
H-S L-A Steel F*	12	9	6	28	81	79	11	11	7	35	80	101	7	5	3	24	57	56
H-S L-A Steel G*	16	10	6	48	102	101	11	10	6	57	120	122	7	4	3	32	53	96
H-S L-A Steel H*	13	9	6	35	80	90	13	13	9	45	124	145	7	4	4	28	82	81
Wrought Iron	10	7	5	31	42	61	13	12	7	41	82	99	8	5	4	46	77	61
3¼ Percent Ni Alloy Steel	10	8	4	27	84	90	10	11	M	35	95	M	7	5	3	27	60	67
3¼ Percent Cr Alloy Steel	17	11	8	63	94	98	3	3	M	32	48	M	3	2	2	12	43	57
18-8 Mo-Cb	.02[2]	0[2]	0[2]	3	1	14	.01[2]	.01[2]	.01[2]	1	67	68	0[2]	0[2]	0[2]	1	0	1
Str. Copper Steel	15	10	6	37	134	105	11	14	8	50	94	88	7	5	4	25	51	49
Str. Carbon Steel (C 1020)	13	11	5	27	92	68	13	13	8	50	136	104	7	5	4	30	57	69
Average	14	10	6	..	...	...	11	11	8	..	...	...	7	4	3	..	..	..

[1] Compositions in Table XI.

[2] Not included in average.

M Missing.

* H-S L-A indicates high-strength low-alloy steel.

partment; thus, for the Mississippi River the values in Table VII are about half those that would have been obtained if the test had been made in free-flowing water. Because of flowing ice, it is impractical to make long-time tests in the free-flowing water at the location originally selected in the Mississippi River.

2. Sea Water

It is of practical importance to know whether the corrosion rates of steels exposed in sea water decrease with time as they do in the atmosphere and to a lesser extent in fresh waters. From results of tests in which specimens were removed from sea water after 5, 10 and 15-year intervals,[26] it has been postulated that during these exposure periods the attack on structural steels was essentially linear. These tests were made at four widely separated locations: Plymouth, England; Halifax, Nova Scotia; Colombo, Ceylon, and Auckland, New Zealand.

In a test of several steels immersed in sea water at Kure Beach, N. C., a slight decrease in corrosion rates with time was found for most grades when the periods of uninterrupted exposures were as short as 1.5, 2.5 and 4.5 years (Table IX). From the above two tests it appears that a slight decrease in corrosion rate occurs during the first few years after which the average corrosion rates of most steels in sea water will be constant and will amount to about 3 to 5 mils per year.

Extensive immersion tests of many steels have been made in the Canal Zone.[27] Test specimens ¼-inch by 12 by 12 inches were exposed in the tidal zone of sea water and were also continuously immersed in brackish water and in fresh water. Specimens were removed after exposure times of 1, 3 and 5 years. Some results, including those obtained on specimens of several high-strength low-alloy steels, are given in Table X, and the compositions

TABLE XI

Compositions of Materials Exposed in the Panama Canal Zone Corrosion Test

DESIGNATION	PERCENT									
	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Others
H-S L-A Steel A*	0.07	0.40	0.088	0.034	0.43	0.42	0.52	0.73	.....	.....
H-S L-A Steel B*	0.07	0.31	0.114	0.042	0.51	0.37	.....	0.68	.....	.....
H-S L-A Steel C*	0.10	0.65	0.087	0.037	0.18	0.52	0.28	0.47	.....	.....
H-S L-A Steel D*	0.11	0.76	0.009	0.023	0.008	1.00	1.18	.....	0.14	.....
H-S L-A Steel E*	0.18	0.46	0.032	0.021	0.044	0.72	1.95	.....	.....	.....
H-S L-A Steel F*	0.14	1.22	0.012	0.032	0.22	0.15	0.08	.....	.....	0.10 V
H-S L-A Steel G*	0.11	0.56	0.018	0.021	0.79	.....	.....	0.47	.....	0.09 Zr
H-S L-A Steel H*	0.18	0.84	0.016	0.034	0.23	0.30	0.18	0.41	0.22	.....
Wrought Iron	0.01	0.03	0.138	0.022	0.09	.....	.....	.....	.....	2.38 Slag
3¼ Percent Ni Alloy Steel	0.14	0.43	0.016	0.037	0.21	0.17	3.25	.....	.....	.....
3¼ Percent Cr Alloy Steel	0.07	0.38	0.021	0.004	0.31	.....	.....	3.27	.....	.....
18-8 Mo-Cb	0.05	0.76	.....	.....	2.10	.....	12.51	18.78	1.79	0.65 Cb
Str. Copper Steel	0.17	0.42	0.015	0.029	.....	0.25	.....	.....	.....	.....
Str. Carbon Steel (C 1020)	0.17	0.52	0.020	0.031	.....	.....	.....	.....	.....	.....

* H-S L-A indicates high-strength low-alloy steel.

of the steels are given in Table XI. It is seen in Table X that during five years of exposure in brackish water, the average corrosion varied from 6 to 9 mils per year. In fresh water the calculated rates were lower, i.e., 2 to 4 mils per year. In sea water (mean-tide position), the corrosion rates varied from 4 to 8 mils per year. No explanation is given as to why the total average loss during three years' exposure in the mean-tide zone was the same as during the 5-year exposure period. Results of longer exposures will be awaited with interest. This anomalous behavior was also found with some of the materials in brackish water. In the fresh water of Gatun Lake rates during five years are about of the same order as the corrosion rates in the Monongahela River, Table VII.

As previously mentioned, LaQue and Hudson state that the presence of chromium increases the corrosion resistance of steels to water. This statement has been substantiated by the tests at Kure Beach and the Canal Zone, where it was found that 2 to 3 percent of chromium is required to appreciably decrease the rates of attack when the steels are immersed in sea, brackish or fresh waters. Whether the increased cost of such steels could be justified by sufficiently longer service life is open to question. It is of interest that in the Canal Zone test in mean-tide position, Table X, the corrosion of the 3¼ per-

cent chromium steel was the highest of 11 steels in the test; but in brackish and fresh waters, its corrosion was the lowest of any material except 18-8 Mo-Cb.

Pitting is one of the important phenomena in corrosion of steel by waters. Although local oxygen-concentration cells are probably responsible for most pits, certain steels appear to have more resistance to pitting than does structural steel. Speller[28] reports that after two years of exposure in aerated Pittsburgh water at 140 F, a 3 percent chromium steel pitted less than any of the other steels tested. In Table X it is seen that after three years of exposure (considered because many specimens were missing after five years of exposure) in both brackish and fresh waters, the 3¼ percent chromium steel pitted less deeply than any other material except the stainless grade. In sea water (mean-tide position), however, this was not true. In this Canal Zone test, the ratio of the depth of the deepest pit to the calculated average attack is higher than that for specimens exposed in the United States, possibly because the higher average temperature of the water in the Canal Zone accentuated the cause of the localized pitting.

In comparisons of pitting in fresh water, in sea water and in brackish water (Table X) it is found generally that pitting is the deepest in the latter two types of water. The presence of certain types of marine organisms may account for the greater prevalence of small areas that are anodic to the much larger surrounding areas, which would account for extensive pitting attack in such waters. From the above it appears evident that the composition of the water, particularly its oxygen content at local regions, plays a major part in the pitting on all steels.

When chemicals are added to water, as in certain industrial applications, no predictions can be made as to the probable relative corrosion resistance of different grades of steel used for equipment. A test under service conditions is the only method by which any practicable distinction can be made and the length of the test should be such as to permit all the variables to influence the final result.

3. *Effect of Contact of Structural Carbon Steel With High-Strength Low-Alloy Steel*

When two dissimilar metals such as copper and zinc are in electrical contact and immersed in an electrolyte, a galvanic cell is formed. The resulting current flow will cause the anodic metal to corrode more than it would when exposed separately in the same environment. When some high-strength low-alloy steels are in contact in sea water with an equal area of structural carbon steel, the resulting flow of current will partly "protect" the high-strength low-alloy steel. If the anode is much larger than the cathode, nearly complete protection of the cathode may be obtained. An example of a commercial application in this principle is the use of nickel-steel rivets (cathode) in carbon-steel ship plates (anode) immersed in sea water.[2]

The lower conductivity of fresh waters diminishes the flow of galvanic current. In the tests reported in Table VII, riveted couples of Cor-Ten steel and structural carbon steel were also exposed. In the Monongahela River, the Cor-Ten steel was protected to some extent. In the Mississippi, there was no appreciable effect. In the Allegheny, the flow of current must have been reversed because the structural steel was protected to some extent and the Cor-Ten steel in contact with the structural steel was corroded more than Cor-Ten steel exposed alone.

Tests by Humble[29] have shown that corrosion rates obtained on continuously immersed specimens are not applicable to steel structures that are exposed alternately both to air and to sea water. Humble reported that steel surfaces immediately below low-tide zone were anodic to that portion of the same steel in the tidal zone. This results in an accelerated attack on the steel immediately below the low-tide zone and a partial protection of the surface in the tidal zone. Because of this effect, the data obtained by exposure of specimens in the tidal zone only (as in Table X) would be of no value for estimating the probable attack on the tidal-zone section of a steel structure such as piling.

Corrosion in Soils

Many tests have been made by the National Bureau of Standards[30] by burying specimens of various grades of steel in soils at many different locations. To date, a total of about 125 test sites have been used. The results show that the type of soil is of much greater importance in determining the severity of corrosion than are the slight differences in composition between the carbon steels and the high-strength low-alloy steels. Both types of steel behave about the same within the limits of reproducibility of the tests.

It has been stated[30] that oxygen-concentration cells are an important factor in the pitting type of attack that frequently occurs on steels buried in soils. All the data from soil-corrosion tests and most of the observations from practical experiences with soil corrosion have been obtained from specimens or structures placed in an excavation that was then refilled with soil. The mixing of the various layers of soil during the refilling process probably affected the oxygen content of the fill and may account for some of the pitting attack. The corrosive conditions adjacent to the steel when it is driven into soil, such as those that occur with steel piling, are very different from those that exist when steel is buried in a trench. In driven-piling applications, it is doubtful whether there is any available oxygen at distances more than a few feet below the surface of the ground. This eliminates the possibility of local oxygen-concentration cells and explains the relatively uncorroded condition of a 121-foot steel bearing pile that was extracted after 17 years in the ground near New Orleans, La., and reported by Greulich.[31] The upper three feet of the pile, which was in the range of the variable water table, was the only area attacked; here about half the area had been "etched" about 0.001-inch. If the pile had been high-strength

low-alloy steel, the results would probably have been the same.

Industrial-Equipment Design

Steel users have taken advantage of the combination of high strength and superior atmospheric-corrosion resistance possessed by the high-strength low-alloy steels. About 100 individual types of commercial applications of these steels are on record. Examples of applications involving large tonnages of these products are railroad cars, farm equipment, mine equipment, boats, trucks and earth-moving equipment. In many of these applications, advantage can be taken of the higher strength of these steels to obtain reduction in equipment weight and still maintain good service life. In other applications, the superior corrosion resistance results in longer service life when these materials are used to replace equal thicknesses of carbon steel or copper steel.

In addition to the well-known cathodic protection method, Vernon[32] lists four other ways of minimizing the corrosion of structures:

1) Methods based on modification of design,
2) Methods based on modification of environment,
3) Methods based on modification of metal (addition of alloying elements, and
4) Methods based on protective coatings (metal or organic).

If a steel is to be used in contact with a liquid, addition of an inhibitor to the liquid will usually decrease corrosion. The environments in which structural steels are used can rarely be changed appreciably but the other three methods are worthy of consideration in attempts to decrease corrosion losses. A comprehensive treatise covering the many dangers of improper design and the use of certain methods of alleviation has been prepared by Mears and Brown.[33]

As previously mentioned, about 100 individual types of equipment used by industry have been made, wholly or in part, from the high-strength low-alloy steels. To obtain full advantage from the improved corrosion resistance of these steels, the following precautions should be observed:

1. The design of the structure should be such that good drainage is obtained and no laps or ledges exist to hold moisture.
2. Adequate protective measures should be applied in those areas that will remain moist for considerable lengths of time.

The two most common protective measures are metallic and organic coatings. Coatings of zinc are frequently applied by hot-dip methods to steel intended for use under severe conditions; for example, roofs of railroad refrigerator cars.

There is evidence[34] that the zinc-steel alloy layer on some galvanized high-strength low-alloy steels is more resistant to some corrosive conditions than the alloy layer on galvanized carbon steel.

Sprayed metal coatings of zinc or aluminum are also widely used. The corrosion resistance of these coatings is shown by Meyer[35] to be a function of their thickness and freedom from pin holes.

Paints and the preferred methods of application have been the subject of many investigations, some of which are discussed by Liebman[36] and Frye.[37] The superior performance of paints on high-strength low-alloy steels over the performance on carbon steels has been discussed previously in this paper.

One of the most important applications of the high-strength low-alloy steels is for railroad hopper and gondola cars. Tice[38] and Kelly[39] have presented papers which contain data showing that the service life obtained by the use of certain high-strength low-alloy steels in open-top railroad cars is greater than that obtained by the use of carbon or copper steels. These papers emphasize that design, as mentioned above, is particularly important.

Accumulations of coal leachings have been found to be very corrosive to steel.[17] In a one-year test, distilled water in amounts equivalent to normal rainfall was added to a 7-foot column of bituminous coal in a stainless-steel cylinder. Leachings, collected at the bottom, contained up to 16 percent ferric sulfate after a three-month period. At the end of a year, the concentration was about 2 percent. No free acid was found. Since such leachings are severely corrosive to all steels except to stainless grades, designing to prevent accumulation of moisture is very important with respect to the service performance of railroad equipment.[40, 41]

Summary

The effects of differences in environment on the corrosion resistance of steels have been shown to be of such importance that tests in a particular environment are necessary to determine the suitability of any type of steel for use under these conditions. Estimations can be made from the results of tests in other locations only if the environments are similar.

Data have been presented which show that the atmospheric-corrosion resistance of certain high-strength low-alloy steels is several times greater than that of structural steel. The comparative atmospheric-corrosion resistance of each individual grade of steel in any one environment is determined by its chemical composition. The superiority of one steel over another with respect to atmospheric- corrosion resistance is thought to be caused by differences in the protective qualities of the rust that forms on fully exposed surfaces of these materials. On surfaces that are sheltered these differences are less pronounced, however, the high-strength low-alloy steels are still somewhat more resistant to atmospheric corrosion than are the structural copper and structural carbon steels.

In most natural waters and soils, the presence of small amounts of alloying elements in the steel does not play a major part in determining the average corrosion rates. However, most steels containing up to 3 to 4 percent of alloying elements do not pit so severely as do structural carbon steels. For structural steels and low-alloy steels, environment is considerably more important than composition.

Short-time service tests will determine only gross differences in probable corrosion rates; longer exposures are necessary to establish differences between most materials.

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All-Plastic Materials of Construction For Corrosive Environments ★

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Abstract

A new group of "construction" materials—materials which can be used to fabricate processing equipment and unsupported pipe are now available to the corrosion engineer. These materials—plastics—are sometimes unknown to the corrosion engineer. The concept of plastics as self-supporting structural material for anti-corrosive applications requires familiarity with them technically and economically.

While hardly a plant in the chemical and allied field does not use plastics as coatings, adhesives, linings, gaskets, etc., the use of corrosion-resistant all-plastic piping and tubing and of all-plastic chemical processing equipment is a recent development which is finding rapid acceptance.

The technological and economical aspects of this group of "construction" materials are discussed. Through discriminate and proper applications—some of which are shown in illustrations—plastics are becoming extremely valuable tools in the constant fight against corrosion.

Introduction

SINCE their early days, the chemical process industries have been able to draw upon metals, wood, cements, brickwork, glass and ceramics of all types for the manufacture of equipment and apparatus which would resist the corrosive action of the various chemicals employed. Despite this variety of means to combat corrosion, chemical plant engineers encounter difficulties daily as a result of corrosive attack on parts of their plants.

During the past thirty years a new group of materials—plastics—primarily of the organic synthetic type has been finding steadily increasing use in the chemical industries. Many of these plastics have been found to offer exceptional resistance to corrosive environments. This exceptionally good chemical resistance of many plastics was recognized very early. Because they do not conduct electricity, they reduced electrolytic corrosion and were, therefore, especially useful in certain corrosive environments where neither special alloys nor other materials could serve satisfactorily.

Plastics in the Chemical Industries

Recognition of various plastics as full-fledged engineering materials of excellent—and in many cases superior—anti-corrosive properties is gaining rapidly. The great number of plastics produced in recent years has broadened the scope of applications in the corrosion protection field so much, that corrosion engineers should find interesting to know more about these synthetics, their properties, advantages and limitations.

Unfortunately, because of the great number of types of plastics available, the generic names of their composition, and the trade names designating the various marketed materials and products, a situation which frequently is confusing to the engineer interested in investigating the potential uses of plastics has been created. In view of their short history as corrosion resistant materials, it may be difficult to estimate and survey fully the potential of all plastics in this field. Although new developments are extremely rapid, an attempt will be made here to present the "status of plastics" in the field of technical corrosion prevention with particular attention to experience gained in the use of all-plastic pipe and all-plastic equipment.

There are now more than thirty chemically distinct plastic families. It must be understood that many types may be made in several different physical forms, or can be blended or copolymerized with other types, or combined with fillers of various kinds. Also, because various blends between resins and synthetic rubbers must be included, an enormous number of compounds results. While only a relatively small number of these have been evaluated, it can be stated safely that there is hardly any plant in the chemical industry which does not make use of plastics in one form or another. This is done not only with the aim of prolonging equipment and apparatus life but also to improve product quality.

The incorporation of plastics in such products as soaps and detergents, cleaning and polishing agents, and in cosmetics, does not ordinarily receive much attention, but this practice contributes considerably to development of the products.

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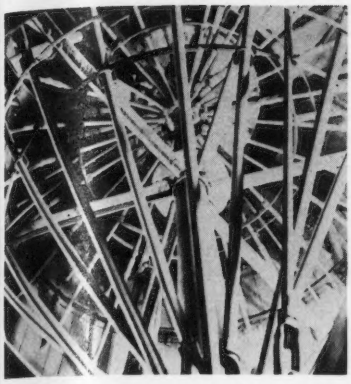

Figure 1—Interior of a new sewage disposal unit. The pipe is made from a rubber-resin blend thermoplastic selected for corrosion resistance, high impact strength and installation ease. (Photo U. S. Rubber Company.)

Figure 2—Four-inch diameter cellulose acetate butyrate pipe assembled on the surface is being moved into ditch, leaving slack to compensate for changes in length resulting from temperature differences. The pipe is to carry crude oil. (Photo Eastman Chemical Products, Inc.)

Figure 3—This heat exchanger for a process involving corrosive mineral acids has 1-inch diameter unplasticized polyvinyl chloride pipe in a frame of the same material. (Photo American Agile Corp.)

Plastics in Technical Corrosion Prevention

The use of plastics as corrosion-resisting materials to lengthen equipment life is not new. In a French scientific review published in 1910, Francis Beltzer commenting on the recently developed "Bakelite" said this new plastic, which was resistant to both concentrated and dilute mineral and organic acids, would permit the manufacture of apparatus, containers and tanks which would advantageously be used in the chemical industries. He foresaw that in the near future modern chemical industries would find available apparatus, equipment and pipe which were both fully corrosion-resistant and practically unbreakable and he also predicted the use of such plastics in paints, varnishes, coatings and linings for various anti-corrosive applications of the chemical and allied industries. His predictions are well on the way to full realization.

Generally, the application of plastics in the corrosion-prevention field may be considered under five main headings:

1. Cements and adhesives
2. Coatings and linings
3. Synthetic fibers and films
4. All-plastic piping, fittings, valves, etc.
5. All-plastic fabrications of corrosion-resistant equipment and apparatus ranging from acid pumps to complex exhaust systems.

This article will be limited to a survey of the present status of the last two groups, where plastics fulfill the requirements of unsupported independent structural materials.

Frequently designers and users of equipment will ask why plastics should be considered as materials of construction when so many other materials are already available. The answer is very simple: In many cases a plastic will do as good or a better job at lower cost. In addition to their light weight and generally easy formability, they offer outstanding resistance to corrosion.

At this point it should be of interest to point out the difference in the mechanism of deterioration of metals and of plastics. In the case of metals, the corrosive attack consists in an actual electrochemical transformation or reaction taking place on the exposed surface. It is important if the products of this reaction form a dense layer which will either retard considerably or possibly terminate further attack. The resulting loss of weight frequently is accepted as a measure of corrosion. In the case of plastics, the main type of attack is not in the form of a chemical reaction, but rather an actual penetration of the corrosive medium into the plastic. The process of attack, therefore, does not take place on the surface, but rather progressively into the material, depending on the period of exposure. This penetration can lead to a complete saturation of the plastic with the corrosive medium, even in the case of heavy wall sections. Instead of the loss of weight characteristic of corroded metals, plastics that have suffered attack will generally show an increase in weight and volume. This combined increase in weight and volume is commonly known as swelling and it is a measure of deterioration of plastic materials. The reason for the different behavior of metals and plastics is primarily in the much denser space lettice of metals, which offer considerably more resistance to an actual penetration of liquids or gases than plastics.

Although the extremely interesting chemical properties and good physical characteristics of many plastics had been realized much sooner, their broad use in piping and particularly as materials of construction for anti-corrosive industrial applications is of rather recent origin, particularly in this country. The latter has been largely due to the sometimes overlooked fact that it is not merely sufficient to have materials of good chemical resistance, but means

must be available for their fabrication into complete structures or units for use in chemical and allied plants. Many of these chemically resistant plastics are not easily joined together and to others mainly because of their chemical inertness, and it has taken time to develop suitable techniques for utilization and fabrication.

While plastics have been recognized and are accepted as standard building materials in many other industrial fields, such as in electrical and electronic applications, the concept of plastics as self-supporting "structural materials" for the chemical industries still seems to encounter some doubts and prejudices. This is despite the fact that many high-grade plastics have been developed for the express purpose of resisting the corrosive action of many chemical agents. In some cases these prejudices are not entirely unfounded. Improper application and poor design and workmanship have caused the plant engineer to be reluctant to consider these corrosion resistant materials.

It is primarily the duty of the specialized fabricator of plastic assemblies and equipment to scrutinize carefully each proposed application so failures will be prevented.

Only a small number of commercial plastics can be considered for use in either all-plastic piping or all-plastic equipment or both. Among thermosetting plastics, the following must be included: phenolics, furane resins, polyesters, epoxy and ethoxyline resins. The desired ultimate properties of the cured thermosetting compounds can be varied greatly by incorporating any one of several inorganic or organic fillers, such as acid-digested asbestos, glass-fiber, cotton webbing, before the curing process takes place, as well as through control of reaction conditions and composition of the mixture.

Thermoplastic materials of importance in manufacture of piping and equipment are: polyethylene, polyvinyl chloride and copolymers, polyvinylidene chloride, cellulose acetate butyrate, polytetrafluoroethylene, polymonochlorotrifluoroethylene, polymethylmethacrylate, rubber-resin blends (comprising a wide variety of compounds ranging from so-called high-impact polystyrenes to blends of styrene-acrylonitrile resin and acrylonitrile-butadiene rubbers). While the thermosetting materials cannot be reformed after their initial setting, the thermoplastics are easily formed and also lend themselves to a greater variety of fabricating processes. In addition to well known basic forming processes—injection and compression molding, high-pressure laminating and extrusion—a wide variety of fabricating methods, such as low-pressure laminating and spraying for the thermosetting, and cementing, hot-gas welding, solvent welding and vacuum forming and drawing for the thermoplastics permit fabrication of many complex types of equipment.

Plastic Pipe

All-plastic pipe was introduced into the field of industrial corrosion protection only a very few years ago. After some rather unpleasant experiences with plastic pipe and fittings during World War II, when they were sold as an untried substitute for metallic materials—primarily for domestic plumbing—considerable progress has been made, both in the quality of the basic raw materials and in manufacturing techniques.

According to most recent surveys, about $7½ million worth of plastic pipe was sold in 1951. Although $7½ million worth of pipe may seem insignificant compared to the value of all pipe sales, it represents quite a record for a virtually unadvertised product which really got its start only three or four years ago. Current estimates are for a market of about $75 million of plastic pipe by 1960.

To achieve such a surprising record, plastic pipe had the following advantages to offer:

1. Resistance to rust, electrolytic action and chemical attack, which cause rapid deterioration of metal pipe. While the initial cost of plastic pipe may sometimes be higher than that for pipe previously used, the longer service life of plastic pipe often offsets this disadvantage.
2. Ease of installation, where the light weight of all plastic piping is a labor saving factor of considerable importance. Furthermore the availability of some plastic pipe in long coiled lengths often eliminates the need for numerous fittings, resulting in a lower "installed" cost, even though metal pipe may cost less per foot.
3. The generally smoother inside surfaces of plastic pipe result in less friction loss in passage of liquids, which often permits the use of smaller pipe size.

Most manufacturers of plastic pipe already are producing more than one type of plastic pipe and tube, which makes it clear that the aim will probably be towards specific applications for each material. The number of types of materials thus employed is growing and their success is assured when restrictions that apply to plastics in an application are observed. There is no all-purpose plastic pipe, nor is there likely to be. The proper material must be chosen to fit conditions of use.

Generally, thermoplastic pipe is not suitable for service at temperatures in excess of 175 degrees F, except for the fluoroethylene polymers which are serviceable up to about 450 to 500 degrees F, and are now making their entry into the industrial piping field as small diameter tubing. Thermosetting plastic pipe can be used continuously or intermittently at temperatures up to 265 degrees F. The temperature factor for thermoplastics is not too great a deterrent in the chemical processing field where untold miles of pipe are needed for transporting various liquids and gases at various operating temperatures.

Among thermoplastics, polyethylene seems to be the most versatile material, combining excellent corrosion resistance with light weight and extremely high impact strength. A recent valuable addition to this field is an industrial pipe made of completely pure polyethylene without added pigment, resulting in a translucent pipe with the full corrosion resistance of polyethylene.

Like polyethylene, the stronger and more rigid polyvinyldene chlorides, high impact polystyrenes and rubber-resin blends are found increasingly in a

wide variety of chemical and allied applications, such as in carrying acid, caustic or electroplating solutions, in rayon processing plants, in chemical laboratory waste systems and also as conduits for electrical lines in corrosive atmospheres. Cellulose acetate butyrate, which is available either transparent or opaque is used in oil fields primarily to handle sour crudes, paraffin crudes and raw gas.

In addition to the previously mentioned fluoroethylene polymers, a newcomer in the thermoplastic pipe field is polyvinyl chloride pipe. It offers excellent chemical resistance with high strength and is now becoming commercially available in this country after being widely used in Europe for about twelve years, often as a satisfactory replacement for copper and steel.

The use of filler-reinforced thermosetting pipe is not new. Glass-fiber reinforced phenolic pipe has been available on a custom-made basis for some time, but only recently has the production of standard glass-reinforced polyester pipe reached proportions sufficient to supply a constantly growing market. The great advantages of this type of pipe are high strength and light weight (the strength-weight ratio is in excess of steel, aluminum or magnesium) impact resistance in excess of that of most metals, wide operative temperature range (60 degrees to 275 degrees F) high working pressure and excellent corrosion resistance.

There is considerable room for improvement in the production of plastic pipe fittings and all-plastic valves as well as an urgent need for standards of quality and size for the various types of plastic pipe now marketed. Such standards will greatly reduce present confusion among potential users and protect them against inferior quality. An industry group to establish such standards has been formed recently.

All-Plastic Apparatus and Equipment

Employment of plastics as materials of construction in the manufacture of corrosion-resistant equipment and apparatus is constantly increasing. There exist in the chemical industry numerous corrosive conditions where the customary expected equipment life can be greatly lengthened with plastics. Although the main reason for their use is their outstanding chemical resistance, other aspects such as low specific gravity, versatile forming and fabricating qualities, and others are important.

The thermosetting materials offer higher strength and higher temperature limits than the thermoplastics, but their fabrication is generally more costly, particularly when only a limited number of units is concerned. They are fabricated either by casting or by low-pressure laminating of the usually filled-resin compound and subsequently cured at elevated temperature. These processes require more or less expensive molds and forms which naturally are of considerable effect on the ultimate cost. Filler-reinforced thermosetting materials, such as asbestos-filled phenol-formaldehyde resins have been available as custom-built equipment and parts for many years. In recent years, glass-reinforced polyesters have made great advances and can be obtained now in custom-built fabrications and as stock products such as storage and process tanks.

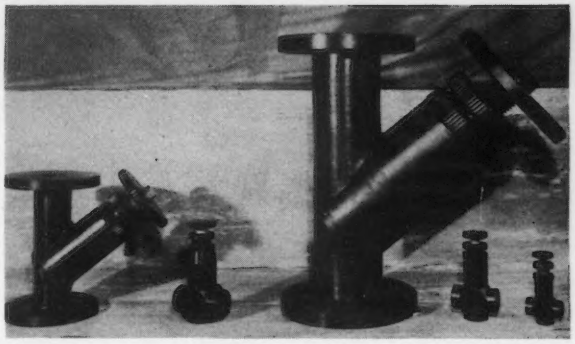

Figure 4—All-plastic valves from ½-inch to 3-inch diameters made of unplasticized polyvinyl chloride except for gaskets or diaphragms which can be made of flexible polyvinyl chloride, neoprene or other materials. (Photo American Agile Corp.)

Cured furfural alcohol resins containing various types of fillers, primarily graphite and the recently introduced epoxy and ethoxyline resins round out the thermosetting types used as construction materials.

Although the thermoplastics offer a more limited temperature operating range, they frequently excel the thermosetting materials in chemical resistance, particularly against alkaline and strongly oxidizing media. They lend themselves to several versatile and economical methods of fabrication which make possible the manufacture of both custom-made and standard-built units without special molds and dies. In addition to the most common method of fabricating thermoplastics (i.e., heat forming under pressure or through vacuum and joining of individual sections by chemical cementing) the hot gas welding method has made it possible for polyethylene and unplasticized polyvinyl chloride to become outstanding construction materials among the thermoplastics. An interesting combination of rubber-resin blend structural sections connected by solvent cementing is being used, although they definitely are limited to the transfer of gases, while welded polyethylenes and polyvinyl chlorides become completely liquid proof structures.

Because there is no satisfactory method of joining sections of fluoroethylene polymers, these extremely valuable materials are not adaptable for structural use for the time being. The development of joining methods will certainly open a tremendous field of application for them.

Temperature and strength limitations make it evident plastics can successfully replace and improve on previously used corrosion-resisting structural materials in a somewhat restricted field only. It is advisable to consult the manufacturer or fabricator of the selected plastic about the application desired because both have accumulated considerable information on correct use, which they willingly pass on. To illustrate the potentialities of plastics for equipment and apparatus construction, some typical applications

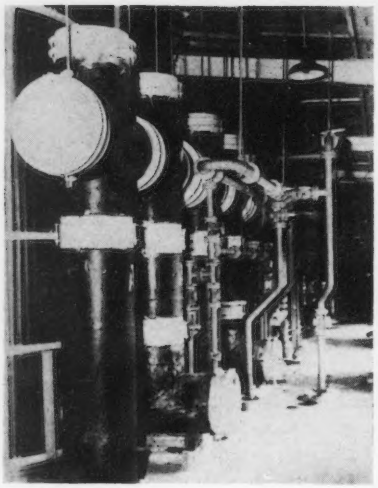

Figure 5—Chlorine gas heaters a foot in diameter and six feet high are made of asbestos filled phenol formaldehyde. (Photo Haveg Corp.)

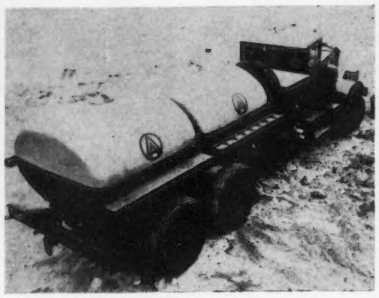

Figure 6—These truck-mounted fuel tanks are made of glass-reinforced polyesters because of their high strength, light weight and resistance to automotive fuels. (Photo American Cyanamid Co.)

Figure 7—A 40-gallon acid makeup tank with baffles, split removable cover and fittings made of polyethylene. This welded tank was substituted for a special alloy tank which had to be replaced at frequent intervals. (Photo American Agile Corp.)

in the chemical and allied industries are depicted in figures included in this article. These few examples serve only to indicate to the chemical plant and design engineer the possibilities.

Exact technical and economic comparison between plastics and other structural materials is a rather complex matter, because in addition to raw material cost and weight factors, one must include such considerations as special molds, forms, reinforcements, the cost of semi-finished sections and other unusual fabrication costs.

Conclusion

The constant growth of the chemical industry increases and complicates the problems of corrosion. Recommendations for the use of plastics in anticorrosive applications require considerable experience and a sense of responsibility. The diversified experience of specialized fabricators therefore is of great importance. Many of these fabricators have shown considerable courage and ingenuity in carrying out much pioneer work. It is advantageous for the chemical industry to become fully acquainted with the possibilities and to make full use of the constant improvement in these materials.

There is little doubt that, if every corrosion or chemical plant engineer were to look around his own plant, he would find that plastics could solve at least some of his worries and in many ways improve the efficiency of his plant and product quality. It may not be an exaggeration to say that there is no chemical plant where plastics cannot be used to some advantage. Intelligent observation and understanding of the advantages and limitations of plastics is all that is required.

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Figure 1—Filiform under clear lacquer on can cover. (Approx. X 2.5.)

Filiform Corrosion*

By M. VAN LOO,* D. D. LAIDERMAN** and R. R. BRUHN*

Abstract

Filiform corrosion is a thread-like type of corrosion which develops under protective coatings on certain metals, usually in humid atmospheres. It is characterized by directional growth and definite structure. Controlling factors are the physical nature of the coating and the exposure conditions. Normally each growing thread consists of an active head of an unstable corrosion product and an inactive body of a stable corrosion product. Filiform corrosion usually appears in an apparently haphazard or disorderly pattern. However, its growth is uniform and orderly in direction, rate and dimensions when developed under controlled conditions. The tracks do not cross one another but deflect or join in a predictable manner.

To date no direct relationship has been found between filiform corrosion and the metallurgical pattern of the surface, the presence or absence of light, biological activity or the presence of inhibitive pigments. It has been observed under both non-metallic and metallic coatings, provided that the coatings are semi-permeable and are sufficiently elastic to yield without rupture to the volume of the oxide formed.

A theoretical explanation is offered for filiform corrosion, involving an initiating force, a driving force and a directing force. It is suggested that corrosion anodes are initiated by an electrolytic mechanism as in ordinary corrosion. The driving force is the diffusion of the corrosive atmosphere into the active head, resulting in further metallic corrosion. The directing force is explained on the basis of concentration cells.

Introduction

FILIFORM CORROSION is a special type of rusting which occurs on certain metals under protective films and is characterized by a thread-like track. Its directional growth and definite structure differentiate it from the usual general or "random" rusting with which all are familiar. It occurs much more frequently than has been recognized previously and has become a matter of serious concern, especially to industrial finishers.

Filiform is usually observed as a maze or network of threads having an apparently haphazard pattern. Examples are shown in Figures 1, 2 and 3. Figure 1 shows a portion of a blackplate can cover coated with a clear lacquer. The dark threads are filiform corrosion of the metal under the clear lacquer film. Figure 2 shows a portion of the metal housing of a laboratory hygrometer with its enamel finish removed after several years of service. Again the maze of dark threads are filiform which are etched into the metal, showing that the metal has corroded. Once this type of corrosion has been recognized and identified it will be observed with rather surprising frequency. On occasion it may be found on such things as jelly can covers, tools coated with a film of oil, refrigerator doors, coated metal tile and on chromium plated automobile hardware, to mention only a few.

Examination of filiform growing under clear films on steel reveals that under normal conditions each active, growing thread has a distinct head, usually V-shaped and blue in color, suggesting that the corrosion product is in the ferrous state. The body of the thread usually has the characteristic red oxide color of the corrosion product in the ferric state. Figure 3 is a magnified photograph showing a portion of an inactive body and part of a growing thread with a V-shaped active head.

C. F. Sharman used the very descriptive term "filiform" in an article "Underfilm Corrosion of Lacquered Steel Surfaces" published in Nature in 1944.[1] He described the phenomenon in considerable detail and his discussion was of great value in selecting the path to follow in this investigation. British interest in filiform corrosion has continued, as evidenced in a recent meeting of the Corrosion Group of the Society of Chemical Industry.[2]

Occurrence of Filiform

In the initial work filiform was found mostly on ferrous surfaces, but subsequently active growth was

★ A paper presented at the Ninth Annual Conference, National Association of Corrosion Engineers, Chicago, Ill., March 16-20, 1953.
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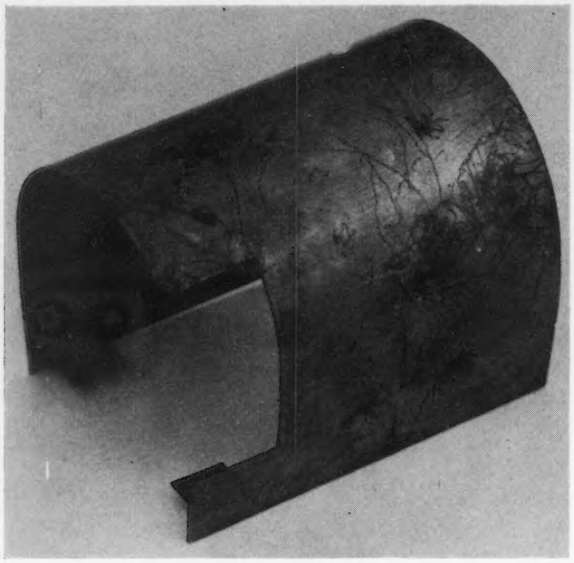


Figure 2—Filiform on stripped hygrometer housting. (Approx. half size.)

observed on magnesium. It has also been detected on aluminum. In this investigation filiform has been developed under tinplate, silverplate, goldplate and certain phosphate coatings on steel. Filiform has not been developed on the more corrosion resistant forms of stainless steel, or on Monel, copper, brass, nickel, chrome, tin, lead, gold or titanium.

The coverage of vehicle types represented in the coatings under which filiform has been observed is by no means complete. However, a considerable number have been examined, such as drying oils and oleoresinous binders, pure and modified phenolic varnishes, alkyds including amine modifications, lacquers, vinyl copolymer coatings and amine modified ether resin and ether ester coatings, in both clear and pigmented films. This at least suggests that the type of binder is not critical.

TABLE I
Underfilm Corrosion of Steel at Various Relative Humidities Over H_2SO_4 Solutions

Relative Humidity	Type of Underfilm Corrosion	Width of Filiform	Type of Active Head	Corrosion Rate	Color of Final Corrosion Products
0–65%	None	.....	.....	.....	.....
65–80%	Filiform	Very thin	Very deep "V"	Low	Light yellow
80–90%	Filiform	Wide	Shallow "V"	Medium to high	Rust colored
93%	Filiform	Very wide	Flat or double "V"	High	Brown and black
95%	Mostly blisters; scattered filiform	Very wide	Flat or double "V"	High	Yellow, brown and black
100%	Blisters	.....	.....	Initially high, decreases rapidly	Rust and black

Perhaps the most valuable contribution of the early work was the indication that a definite connection exists between filiform growth and humidity, when it was observed that filiform generally occurs when humidity is relatively high. Cold rolled steel panels coated with a baked enamel were each scribed in an X pattern and rusting was initiated by exposure over acetic acid solution as will be described later. The panels were then exposed to a series of atmospheres ranging from less than 5 percent up to 100 percent relative humidity, all at 75 degrees F. In one series the humidity was controlled by using solutions of sulfuric acid of the proper concentrations, in the second series through the use of sodium hydroxide solutions. No filiform was observed below 65 percent RH but it was quite active between 80 and 90 percent RH. Filiform threads became wide above 90 percent RH and blisters appeared at about 95 percent RH. Corrosion was much more active over sulfuric acid solutions than over sodium hydroxide at equal relative humidities. A general recapitulation of the results on the panels exposed over the sulfuric acid solutions is given in Table I.

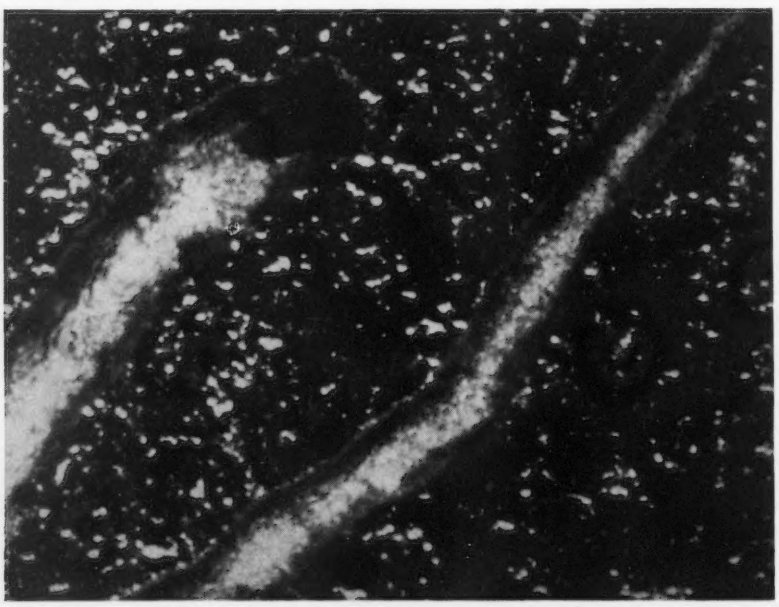


Figure 3—Magnified view of filiform threads showing V-shaped head. (Approx. X 85.)

Preliminary Investigation of Factors Involved

Because filiform corrosion was first called to the attention of the authors in 1944 on theatre equipment, some connection with the relative absence of light or with some phase of air-conditioning was suspected. Any association with the presence or absence of light was disproved almost immediately when filiform was grown in complete darkness, in direct and diffuse sunlight and under artificial illumination.

To date no connection has been

found between filiform growth and biological activity. When conditions exist which are conducive to filiform growth it has proceeded apparently unimpaired under coatings in spite of the presence of toxic agents in amounts which have been found sufficient to prevent bacterial or fungus growth in or on paint films. The fungicidal or fungistatic agents used included various mercurials, chlorinated phenols, cuprous oxide and certain proprietary fungicides which have shown acceptable performance in controlling mildew growth on paints. However biological experts are considering an investigation of this phase and their findings would be of considerable interest.

A frequent suggestion is that the tracks may follow the metallurgical-contours of the metal substrate. A metal surface has been described as a complex or crystal faces, edges, corners, boundaries and disturbed layers.[3] It might well be expected that the tracks would follow along some of these boundaries. However, when samples were shown to metallurgists they found no correlation with the metallurgical topography of the metal surface. The fact that under controlled conditions a single filiform thread may progress a considerable distance with no deviation in direction indicates that in its course the thread may cross numerous surface boundaries without apparent effect. It should be noted also that when cuts are made through the coatings to the metal, filiform threads usually start perpendicular to the scribe marks, whether the cuts are made diagonally, vertically or horizontally on the face of the panel. This again suggests independence of the metallurgy of the surface. In some instances where panels have been sanded (especially true on magnesium) there has been a tendency for the threads to follow sand marks.

Consideration must be given to the thought that inhibitive pigments in conventional metal primers may retard or eliminate filiform corrosion. It would be physically impossible to check every possible primer formulation. However, tests which included all of the usual types showed that under suitable conditions all permitted filiform growth. So-called "wash primers" will permit filiform growth although usually in a retarded form.

Vapor phase inhibitors when added to metal primers did not prevent filiform. Certain surface conversion phosphate type treatments which were examined are beneficial in retarding filiform but do not prevent growth if a scratch or imperfection penetrates the protective film and phosphate coating to the metal. Pretreatment of the metal with mineral oil, vegetable drying oils plus driers or titanium acylates before application of an industrial baking alkyd enamel did not inhibit filiform.

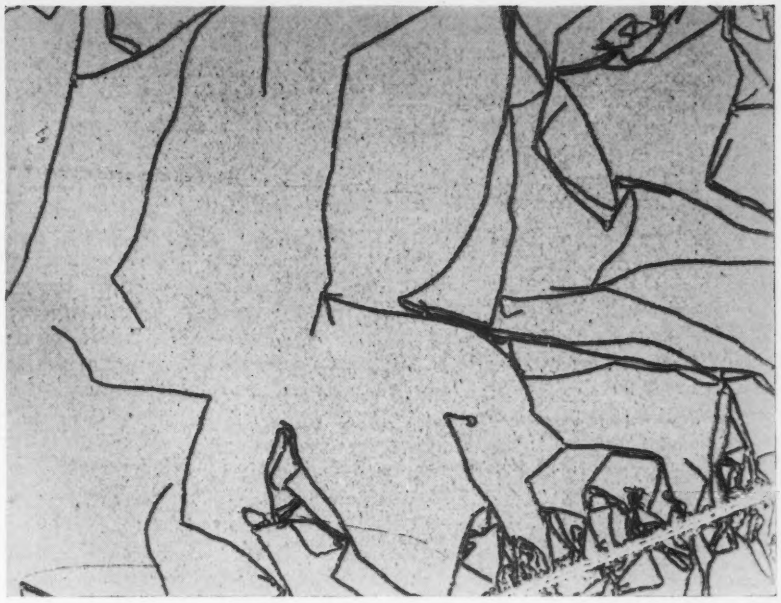


Figure 4—Filiform under clear varnish on cold rolled steel exposed 840 hours to 86 percent relative humidity at 75 degrees F over H_2SO_4 solution. (Approx. X 5.)

Laboratory Study of Filiform

The preparation of a test panel for the study of filiform involves few departures from regular laboratory procedure. As an example, a test may start with a clean cold rolled steel panel coated with a clear or pigmented finish using the recommended reduction and application technique, followed by air drying or baking. An X-mark is then scribed through the coating to the metal. The panel may then be placed in a convenient closed container over 1 percent acetic acid solution for approximately 24 hours to initiate corrosion. The acid activation is not essential and neither the concentration nor the period of exposure is critical. However, the conditions described are adequate and convenient.

After the activation the panel is moved into the test environment and observed for progress of filiform. Figure 4 shows a portion of a test panel on which considerable filiform had developed under a clear varnish after 840 hours' exposure in an atmosphere maintained at 86 percent RH at 75 degrees F over sulfuric acid solution. The threads usually originate from a scratch but they may also start from an edge, a speck, a piece of dust or lint, or any imperfection or discontinuity in the protective film. When grown under reasonably constant conditions the dimensions of the filiform threads are quite uniform. Their lengths are usually many times their respective diameters. Observations by Hargreaves[4] and Kayser[5] suggest that there may be both a micro and a macro form of filiform, although these dimensional differences may have been due to variations in temperature, humidity, thickness of surface coating, etc. As

mentioned earlier, each growing thread observed in work reported here has an active head (blue in the case of ferrous surfaces, black in the case of magnesium) and an inactive body (rust colored in the case of ferrous surfaces, white in the case of magnesium). The filiform channel lifts the surface coating as the film yields to the expansion from the corrosion product of the metal.

If the test panel is removed to an environment not conducive to filiform growth, such as to low humidity, the growth stops, the active head "dies" and usually changes to a yellow oxide color if on steel. Growth will resume if the panel is again placed in a humid atmosphere, but the tracks usually are not merely continuations of the old, but tend rather to start off in a new direction.

When one filiform thread comes into contact with another, several things may happen, depending on the conditions. Limiting the discussion for the moment to ferrous surfaces the authors have not observed that one filiform has crossed the track of another. If the active head of a growing filiform strikes the inactive body of a filiform which has already passed that point the two do not coalesce, but the active filiform deflects at an angle approximately equal to the angle of incidence. In the special case where one active filiform head strikes another inactive thread at an angle of 90 degrees, the impinging filament may cease to grow. However, the active head usually mushrooms and splits into two heads which then reflect, each growing a filiform thread at an angle from the inactive head and the impinging thread. Many interesting cases may be observed where a growing filiform is surrounded by other inactive tracks. In such instances the growing filiform rebounds in a sequence of contacts into a constantly more confined area, and eventually "dies."

If two active heads happen to collide precisely head on they can coalesce. If, however, two active heads reach the same point simultaneously at a slight angle from two directions they can combine and proceed as a single filiform in a direction which is approximately the average of the two original paths. If the junction is not exact, the ensuing single filiform will progress in a path which deflects according to the deviations from such exact juncture.

Filiform corrosion on magnesium is vigorous under suitable conditions. There are some indications that magnesium may show some phenomena which do not fit precisely the pattern which has been described for ferrous surfaces. Further work is required.

Major Factors in Filiform Growth

A considerable portion of the work done by the authors has been devoted to the identification and understanding of the major factors involved in filiform growth. The significant role played by humidity has already been described. Because of the writers' laboratory's interest in critical pigment volume concentration relationships in pigmented coatings,[6,7] it was natural that any possible connection with filiform should receive early attention. Critical pigment volume concentration (CPVC) has been defined as that point at which just sufficient binder is present to fill completely the voids left between the pigment particles after the volatilization of the thinners. It is the transitional point at which substantial changes appear in such characteristics of the coating as gloss, blistering tendencies and permeability, as well as rusting under the film.

Permeability is usually relatively low at low pigment loadings, then goes through the transitional point to a relatively high permeability above the CPVC. Tests of series of enamels varying only the volume ratios of pigment to binder show that filiform corrosion will occur only below the critical pigment volume concentration for each pigment-binder system. Above the CPVC, where there is an insufficiency of binder and the film is porous, only general or "random" rusting has been observed. In very recent work, tests of metal primers show that filiform can grow under primers formulated above their critical pigment volume concentrations when certain rust inhibitive pigments are used. Below the CPVC the films will meet one requirement for permitting filiform, which is that they must be semi-permeable. It should be noted that a filiform in a region of constant permeability tends to grow linearly but tends to bounce away from an interface of much lower permeability. Filiform width increases with increase in film thickness as well as with increase in humidity. A second requirement for a coating which permits filiform growth is that it must have sufficient elasticity to yield without breaking because of the expansion from the voluminous oxide forming underneath.

From the standpoint of the metal substrate, for filiform to occur the metal must have a coating and it must be capable of undergoing corrosion. A limiting requirement is that the free metal must oxidize first to an unstable state and then to a stable state. Corrosion of iron and steel proceeds first to the unstable ferrous state and then to the stable ferric state. Magnesium corrodes to first form the unstable black amorphous magnesium hydroxide which then converts to the stable white crystalline form. Aluminum can meet the conditions because it can form oxides in different states and degrees of hydration.

Theoretical Discussion

Major emphasis to date has been on the identification of filiform corrosion and observation of its nature. Development of a theory to explain filiform has proved to be a complex and difficult assignment. However, on the basis of available data, a theory is offered for consideration.

It has been pointed out that filiform corrosion differs from conventional rusting in two respects. It has a characteristic structure (V-shaped active head and long inactive body) and its growth is directional (linear and regular rather than radial and haphazard). The peculiar bouncing, blending and splitting are secondary differences inasmuch as they apparently result from the same forces which control the filiform structure and direction. The theory offered explains these characteristics by considering three

steps in the filiform process: the initiating mechanism, the driving mechanism and the directing mechanism.

1) *Initiating Mechanism*

Filiform corrosion is primarily an atmospheric phenomenon which is quite sensitive to relative humidity, as was shown in Table I. Extension of this table to immersed aqueous systems provides an interesting comparison of atmospheric corrosion and corrosion during immersion. In the former the corrosion is relatively even and comparatively mild. This suggests a mechanism of atmospheric corrosion in which countless tiny anodes are controlled by adjacent cathodes which are also very small in size. Such a system is plausible because of the lack of strong electrolytic contact between distant areas of the metal surface.

An actual study of the conductivity of surface moisture on a metal surface would be difficult. However, the literature on surface conductivity of dielectrics in humid atmospheres is extensive. Such studies show surface conductivity to be extremely sensitive to relative humidity, with conductivity in general being higher the higher the relative humidity.[8] In immersed aqueous corrosion there is good electrolytic contact between all points. Hence it is possible for large anodic areas to couple with large cathodic areas to form vigorous corrosion cells.

Figure 5 is a diagram of a metal surface partially protected with a paint film. If this panel is exposed to a corrosive atmosphere, the surface corrodes as countless tiny anodes and cathodes as described above. At the film-metal-air junction, (I), many of these voluminous anodes (A) will lift semi-circular portions of film as shown. If this panel is then exposed to a constant relative humidity above 65 percent, the exposed metal in the V-shaped area (L) between the corrosion anodes corrodes. The corrosive atmosphere reaches the area at a rate which is controlled by the permeability of the paint film. In the case of iron, the first product of such a slow corrosion process is the blue ferrous hydroxide which fills the V-shaped area. This is recognized as the active head. The original corrosion anodes (A) are converted quite rapidly to ferric hydroxide, since they are in virtual contact with the corrosive atmosphere. This provides the boundary observed between the ferrous and ferric phases.

Since the corrosion rate of many metals increases with increasing relative humidity, it is apparent that the number of filiform initiated will increase as a matter of chance. (See Table I.) The width of the filiform will also increase because of the more vigorous corrosion taking place at the higher relative humidities. Furthermore, the V-shaped active head will be very deep at the low relative humidities, since the low corrosion rate reduces the chance of overlapping anodes. At medium relative humidities, there is a good chance for the numerous anodes to overlap, resulting in a shallower V-shaped head. At very high relative humidities, there is the possibility of three

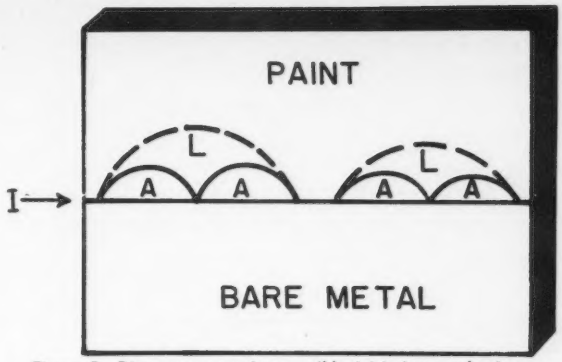
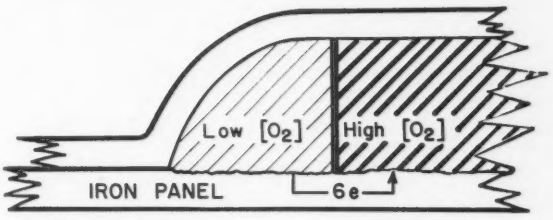


Figure 5—Diagram suggesting possible initiating mechanism.



ACTIVE HEAD

$2Fe - 4e \rightarrow 2Fe^{++}$

$2Fe^{++} - 2e \rightarrow 2Fe^{+++}$

INACTIVE BODY

$6H^{+} + 6e \rightarrow 6H$

$1\frac{1}{2}O_2 + 6H \rightarrow 3H_2O$

Figure 6—Diagram suggesting possible driving mechanism.

anodes combining to produce a filiform. Such a condition would give rise to the double "V" active heads which are observed at about 93 percent RH.

2) *Driving Mechanism*

Briefly, the mechanism associated with the electrolytic theory of corrosion is as follows:

At the anode: $Fe - 2e \rightarrow Fe^{++}$
At the cathode: $2H^{+} + 2e \rightarrow 2H$
Overall reaction: $Fe + 2H_2O \rightarrow Fe(OH)_2 + 2H$

At this stage, depolarization of the cathode is necessary before further corrosion can proceed. This may be effected by escape of molecular hydrogen or oxidation of hydrogen to water. Oxidation of the ferrous hydroxide to ferric hydroxide completes the process.

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$$

As described previously, the permeability of the film to the corrosive atmosphere controls the corrosion process within the active head. Further corrosion causes further lifting of the film which in turn exposes more metal for corrosion. The active head grows slowly in a radial direction. While this corrosion process is taking place at the leading edge of the active head, a process of conversion is taking place at the rear of the head along the V-shaped ferrous-ferric interface. Here the ferrous hydroxide is being converted to ferric hydroxide.

The mechanism which keeps this corrosion-conversion process going is the oxygen concentration cell[9,10] set up by the difference in concentration of oxygen between the active head and inactive body.

The concentration of oxygen in the active head is considerably lower than that in the body. The factors controlling this concentration gradient are:

a. Time Factor. As the film is lifted by the advancing filiform there is a temporary and localized low concentration of oxygen which then rises as permeation of oxygen into the area proceeds, setting up an oxygen gradient.
b. Local corrosion within the active head. Appreciable quantities of oxygen are consumed within the active head by local corrosion.[11] Although such local corrosion undoubtedly proceeds through an electrolytic mechanism, it is independent of the major electrolytic cell in operation—a corrosion cell within a corrosion cell, so to speak. Such corrosion in the active head would consume oxygen through its local depolarization and oxidation reactions.

With the resulting concentration difference, a process of oxidation would result in the active head and a process of depolarization near the ferrous-ferric interface. The existence of oxygen concentration cells was demonstrated conclusively by Evans[9] when he measured the flow of current in the following cell:

$$Fe \mid H_2O\ (O_2\ high) \mid H_2O\ (O_2\ low) \mid Fe$$

The iron electrode immersed in the solution of low oxygen concentration became anodic to the one in the solution of high oxygen concentration. A similar type of oxygen concentration cell would exist in the case of magnesium.

As soon as the ferric hydroxide is formed, radial growth ceases so that the width of the filiform is now determined. Without this reaction, radial growth would continue and normal underfilm corrosion would result. In the case of magnesium, the same general process takes place except that here the first corrosion product is the unstable amorphous magnesium hydroxide while the second product is the stable crystalline magnesium hydroxide.

The reason that the second corrosion product stops radial growth may be found in a study of the protective properties of corrosion products. For example, if the first corrosion product is slightly soluble, it will be formed out of physical contact of the metal surface and hence will not have protective properties. If, however, conditions are such that the corrosion product is formed in physical contact with the metal surface, such a product may have protective properties and may tend to stop further corrosion.[12] The importance of corrosion products as they affect corrosion rate has been pointed out by several workers.[13] It is interesting to note that in the case of filiform corrosion of iron, different corrosion products appear at about 93 percent relative humidity, which is the top limit for filiform corrosion and the threshold of radial corrosion (blistering). (See Table I.) Much work remains to determine the exact identity of the various corrosion products obtained in filiform corrosion, and more important, to determine whether or not some of these corrosion products actually do have protective properties in the relative humidity range of filiform corrosion.

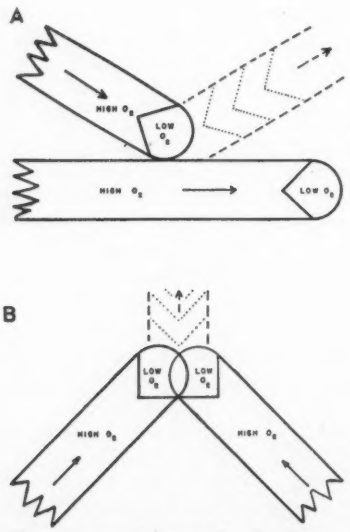


Figure 7—Diagrams suggesting possible directing mechanism.

3) *The Directing Mechanism*

Under conditions of constant temperature, humidity, film thickness and metal surface regularity, filiform will grow in a very straight path. Here, the directing mechanism is the conversion of the initial corrosion product to the final protective corrosion product. This prevents radial growth and imparts linearity. However, the filiform will be deflected from its path when it meets a second filiform as described earlier. If the active head of one filiform meets the inactive body of another, it must deflect since the metal under the inactive body is protected from further corrosion. See A in Figure 7. When the angle of incidence is 90 degrees the filiform may "die." However, when the active head strikes an inactive body at or close to an angle of 90 degrees, it often mushrooms and splits into two heads. As was mentioned earlier, the new threads reflect on either side of the impinging thread. The mushrooming offers a number of directional effects too complex to illustrate in a simple diagram. When two filiform heads meet they blend since neither area is protected at that stage of growth. Also there are no oxygen concentration differences here, so no concentration cell can be set up. Because of the advancing inactive boundaries, the two blend and proceed as one in the direction indicated in B in Figure 7.

Thermodynamic Considerations

It is felt that a thermodynamic treatment of this problem is not justified. Such a treatment would define only the initial and final states of the reactions. Since filiform corrosion is unique in its peculiar structure and behavior such information would contribute little toward the explanation of a problem which is so typically one of mechanism. Furthermore, the system by virtue of its atmospheric occurrence would not justify the use of ionic concentrations in calculation of free energy changes. A greater knowledge of ionic activities and mobilities would be

required. Also the presence of oxygen and its oxidizing and depolarizing effect would complicate matters further. Even in the event that a thermodynamic treatment were justified, consideration of the direction and magnitude of the following concentration and electrolytic cells operating simultaneously with the oxygen concentration cell would be necessary:

(a) $Fe \mid Fe^{++} (C_1) \mid Fe^{++} (C_2) \mid Fe$
(b) $Fe \mid Fe^{+++} (C_1) \mid Fe^{+++} (C_2) \mid Fe$
(c) $Fe \mid Fe^{++} \mid Fe^{+++} \mid Fe^{++}$

Is There a Cure for Filiform Corrosion?

It is now possible to define with fair accuracy when and where filiform may grow. It can be developed for study in the laboratory when desired. However, it would be much better for both supplier and consumer of coatings if means were available to prevent filiform. It requires no great amount of modesty to state that at the moment no cure-all has been discovered.

Much of the metal which receives protective coatings is of the type which can filiform and the amount of replacement possible with non-filiforming substrates is limited. Obviously, if humidities could be held below the range where rusting will appear, the problem would be solved. This certainly is impractical under most circumstances, especially after the coated article has passed into the customer's hands. In the field of product finishing it is advisable to avoid high humidities during the finishing operations, if possible, and especially during storage of the finished product. Reduction of susceptibility to filiform has been reported when phosphatized metal is given a final rinse in demineralized water.[14] This improvement is ascribed to removal of water soluble, ionizable salts or hygroscopic materials from the metal surface prior to painting. Care should be taken to avoid contamination of the paint coating by dust or lint during the finishing operation since such discontinuities may become initiating points for filiform and may serve to wick in moisture. Imperfections in the film and marring should be avoided as much as possible.

Many finishes are required to have gloss, elasticity, durability, etc., which dictate formulation with some free binder, i.e., formulation below the critical pigment volume concentration. Therefore the use of flat finishes of relatively high permeability often is unacceptable. In some instances it is possible to formulate semi-gloss or gloss finishes which are otherwise acceptable and which at the same time will be sufficiently inelastic so that they rupture when filiform develops under the film. This stops growth momentarily, after which the corrosion resumes until the next rupture, with the net result that the amount of filiform may not be objectionable.

Conclusion

Filiform corrosion has been described as differing from conventional rusting in that it has definite structure and directional growth. Typical examples have been described and conditions conducive to filiform growth have been defined. A theoretical explanation is offered involving an initiating mechanism, a driving mechanism and a directing mechanism. No universal cure has been discovered to date, but suggestions are made how to improve the situation.

Much work remains to be done. Further fundamental study is needed in almost all the phases, including micro inspection of the filiform thread, a better understanding of the corrosion process and precise identification of the corrosion products. The scope of this paper does not permit the discussion of certain apparent anomalies that have been observed, such as "headless" filiform and the possibility of branching. Further studies of magnesium and aluminum are indicated.

Acknowledgment

The authors acknowledge the cooperation and assistance of W. K. Asbeck and G. G. Schurr of the Paint Research Department of the Sherwin-Williams Company and contributions by W. H. Slabaugh, now of Kansas State College, who started this investigation while a member of our department and who has maintained an active interest in our work ever since. Many others will recognize some of their suggestions as they appear in the paper and their help is also gratefully acknowledged.

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Accelerating Effect of Decreasing Temperature On Corrosion by Glycol Solutions*

By D. CAPLAN and M. COHEN

DURING the operation of an experimental refrigeration unit in which cold 50 percent ethylene glycol inhibited with borax was circulated in contact with galvanized steel, it was observed that a voluminous white precipitate of zinc hydroxide appeared if the solution was warmed to room temperature. Examination of the unit showed that the zinc had been severely attacked. There was no indication in the literature that glycol corroded zinc at low temperature; in fact, borax was recommended as a satisfactory inhibitor for zinc in glycol automotive antifreeze.[1] The observation seemed interesting enough to warrant setting up a beaker-type laboratory corrosion test.

The corrosion rates of galvanized sheet in ethylene glycol solution and in glycol containing borax were determined at different temperatures. For comparison, the same test was carried out at room temperature with distilled water free from and containing borax. The corrosion rates of a number of other metals in 50 percent glycol and in 50 percent glycol with borax were determined at 20 degrees F. The corrosion rates of galvanized sheet in glycol solutions containing a number of salts other than borax were also determined.

Experimental and Results

All corrosion tests were carried out in duplicate. Blanks were determined for the various metal panel cleaning methods and were used in calculating weight losses which are reported in milligrams per square decimeter per day (mdd).

a) *Test on Galvanized Steel in Glycol with Borax*

Panels measuring 1¾ x 2¼ inches were cut from 26-gauge galvanized sheet, scrubbed with a bristle brush in trichloroethylene, vapor degreased in trichloroethylene and weighed. They were totally immersed in the test solution for 14 days during which time air was bubbled in continuously. Tests with 1:1 ethylene glycol and water mixtures, free from and containing 1 percent borax ($Na_2B_4O_7.10H_2O$), were carried out at —10, 20, 75 and 170 degrees F. At the end of the test, the corrosion products were removed by cathodic treatment in 3 percent Na_3PO_4 — 1.5 percent Na_2CO_3 — 1 percent NaOH solution, dried in alcohol, and reweighed.

Figure 1 shows the weight losses at the various temperatures.

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Abstract

The corrosion of galvanized steel in solutions of ethylene glycol containing borax is found to increase with decreasing temperature. This is believed to be due to the formation of a soluble complex zinc salt, the stability of which is greater the lower the temperature, which prevents the formation of a barrier film of insoluble corrosion product. Cadmium, magnesium and brass are attacked at low temperature in glycol-borax solution by the same mechanism, as is zinc in solutions of glycol containing sodium acetate or sodium benzoate.

It was observed at the end of the test that although the glycol-borax solutions were clear at the testing temperatures of —10 and 20 degrees F, a heavy white precipitate of zinc hydroxide appeared when they were warmed. The precipitate dissolved if the solutions were cooled again. The solutions which did not contain borax did not exhibit this behavior.

b) *Test on Galvanized Steel in Distilled Water*

The same test as above was carried out at 75 degrees F with galvanized steel in distilled water free from and containing 1 percent borax.

The weight losses obtained were 17.9 mdd without borax and 0.1 mdd with borax.

c) *Test on Other Metals*

Panels of brass, cadmium, copper, lead, solder and

magnesium of the same size as those cut from the galvanized sheet were scrubbed with a bristle brush and abrasive soap, dried in alcohol and weighed. They were totally immersed in aerated solutions of 50 percent glycol with and without 1 percent borax as above, except that all the tests were run at 20 degrees F for 28 days. Composition of the metals used in shown in Table I. In addition, the same tests were performed on 2S aluminum, carbon steel, 18-8 stainless steel, nickel, silver, tin, tinplate and titanium, but these test results are not reported because metals tested were found to corrode at a rate less than 0.5 mg/dm²/day, which was considered negligible.

At the end of the test the corrosion products were removed in the following manner:

Brass—cathodic treatment in inhibited 5% H_2SO_4.
Cadmium—cathodic treatment in inhibited 5% H_2SO_4.
Copper—cathodic treatment in inhibited 5% H_2SO_4.
Lead—bristle brushed with acetone and with toilet soap.
Solder—dipped in boiling 1% acetic acid.
Magnesium—dipped in boiling 15% CrO_3 containing 1% Ag_2CrO_4.

Table II shows the results obtained. From the column on the right it can be seen that cadmium, brass and magnesium exhibit a marked increase in corrosion when borax was added as did galvanized steel.

Solutions from the brass and cadmium tests behaved like those of zinc in that the precipitate which appeared on warming the glycol-borax solutions disappeared on cooling and that no precipitate appeared in the borax-free solution so treated. Both the borax and borax-free solutions from the magnesium test gave a precipitate on warming which cleared on cooling.

d) *Test on Galvanized Sheet in Glycol Solutions of Various Salts*

In a similar manner galvanized panels were tested for 14 days at 20 degrees F in 50 percent glycol solutions containing one percent of these salts: sodium nitrite, sodium carbonate, sodium acetate and sodium benzoate.

As shown in Table III acetate and benzoate gave acceleration of attack as did borax, while nitrite and carbonate inhibited somewhat. Heating the solutions from the acetate and benzoate test resulted in a white precipitate which cleared on cooling.

Discussion

Results in Figure 1 show that at 170 degrees F borax is an excellent inhibitor for zinc in ethylene glycol. At room temperature, however, borax acts as a corrosion accelerator in glycol, the corrosion rate being more than twice as great with borax than without. At 20 degrees F the corrosion rate in glycol-borax shows a marked further increase and even at as low a temperature as —10 degrees F the corrosion rate is still high. This anomalous behavior (the authors know of no other instance where corrosion

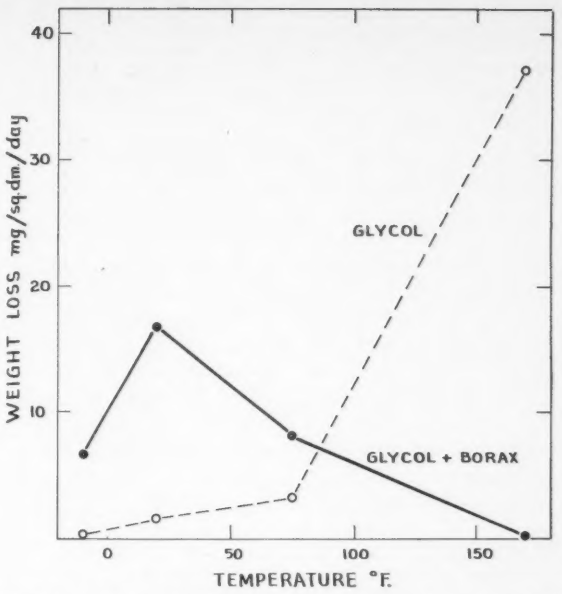

Figure 1—Corrosion of galvanized steel in 50 percent ethylene glycol with and without 1 percent borax. 14-day test.

rate has been reported to increase in this manner with decreasing temperature) is believed to depend on the fact that glycol can form a complex acid with borate[2, 3, 4] and this complex acid, in turn, apparently forms a soluble complex salt with zinc. The formation of the normal insoluble zinc corrosion product is thereby prevented and the stifling of further corrosion does not take place. Since the stability of such complexes decreases with increasing temperature, it follows that the corrosion also will decrease with increasing temperature. This theory is supported by the behavior of the test solutions at the end of the test: although clear when cold, a precipitate of zinc hydroxide appeared on warming and dissolved again on cooling. In the absence of borax the corrosion rate increases with increasing temperature in the usual manner as shown by the broken line in Figure 1.

Results with distilled water at room temperature

TABLE I—Composition of Specimen Materials

Metal	Cu	Pb	Sn	Zn	Ni	Fe	Mn	Other
Brass	68.8	.15	.05	31.2	.01	.03	.003	.....
Cadmium	.01	.05	.002	.....	.....	.01	.....	.....
Copper	Bal.	.....	.....	.....	.03	.05	.....	.....
Lead	.....	Bal.	.....	.....	.01	.05	.....	.....
Solder	.005	57.0	43.0	.....	.....	.....	.....	Sb 0.14
Magnesium	.02	0.1	.....	.....	.....	.05	.004	Si .03

TABLE II—Corrosion in 50% Ethylene Glycol at 20°F.
A—50% ethylene glycol. B—50% ethylene glycol + 1% borax

METAL	Weight Loss in mdd. A	Weight Loss in mdd. B	B/A
Cadmium	1.52	17.5	11.5
Zinc*	1.63	16.7	10.3
Brass	0.11	0.45	4.1
Magnesium	5.21	18.2	3.5
Solder	0.38	0.70	1.8
Copper	0.10	0.10	1.0
Lead	65.4	8.29	0.13

* 14-day test.

TABLE III

Corrosion of Galvanized Sheet in Glycol Solutions of Various Salts at 20°F.

Test Solution	Weight Loss in mdd.
50 percent ethylene glycol	1.63
50 percent ethylene glycol +1 percent sodium nitrite	0.85
50 percent ethylene glycol +1 percent sodium carbonate	0.24
50 percent ethylene glycol +1 percent sodium acetate	2.91
50 percent ethylene glycol +1 percent sodium benzoate	4.05
50 percent ethylene glycol +1 percent borax	16.7

show that, in the absence of glycol, borax is an efficient inhibitor for the corrosion of zinc.

In the tests with the other metals, cadmium, magnesium, brass and solder corrode at a higher rate at 20 degrees F in glycol-borax solution than in glycol solution alone. Copper corrodes at the same rate in both solutions and lead corrodes less in the presence of borax. The results with cadmium, including the behavior of its precipitate on heating and cooling, are analogous to those of zinc and the same mechanism applies as is suggested for zinc: that is, the formation of a soluble complex cadmium salt of the borax-glycol complex prevents the formation of a protective precipitate at low temperature. The behavior of magnesium is also similar to that of zinc, but the fact that a precipitate is formed on warming in the absence of borax indicates the complication of a second effect, which may be caused by the dissociation of a magnesium glycolate on heating. Since the presence of borax increases the corrosion rate of brass but has no effect on copper, it is probable that the zinc content of the brass is undergoing corrosion. The small increase in the corrosion of solder in the presence of borax is probably not significant. Borax inhibits the corrosion of lead. The other metals tested—aluminum, steel, stainless steel, nickel, silver, tin and titanium—are not appreciably corroded at 20 degrees F by glycol solutions either with or without borax.

The increase in attack on brass with borax at low temperature should be of interest to the automotive industry in that radiators are made of brass and borates are very extensively used in the formulation of glycol antifreeze. That this low temperature attack has not been observed previously is not surprising because laboratory corrosion testing of antifreeze is always conducted at elevated temperatures.

Palit[5] discusses what he terms the "glycolic interaction" of compounds having a $-COO^-$ group and extends his discussion to any $-XOO^-$ group where X is any negative element. He shows that carbonates, acetates, benzoates, nitrites, metaborates, aluminates, hypophosphites and metaarsenites, among others, have exceptionally high solubilities in glycol, indicating that glycolic interaction occurs. Results from the corrosion test on galvanized panels in glycol solutions containing acetate, benzoate, nitrite and carbonate indicate that with acetate and benzoate this glycolic interaction leads to corrosion of zinc by the same soluble complex mechanism as outlined for borax.

Conclusion

1. Borax, although an inhibitor of the corrosion of zinc by glycol solutions at elevated temperatures, acts as an accelerator of corrosion at lower temperatures, the rate of corrosion increasing with decreasing temperature. The mechanism of this behavior is believed due to the complex acid which borate forms with glycol and the soluble complex salt this acid apparently forms with zinc and to the fact that such complexes are more stable at lower temperatures. This permits active corrosion to proceed since a barrier film of corrosion product is prevented from forming.

2. Of the other metals tested, brass, cadmium and magnesium behave similarly to zinc, the brass apparently because of its zinc content.

3. Aluminum, steel, stainless steel, nickel, silver, tin and titanium do not corrode appreciably in glycol or glycol-borax at 20 degrees F. Copper corrodes slightly but equally in both solutions. Lead corrodes much less if borax is present but solder a little more.

4. Sodium acetate and sodium benzoate in glycol solutions are corrosive to zinc at low temperature by the same soluble complex mechanism as for borax.

Acknowledgment

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Corrosion by Aqueous Solutions At Elevated Temperatures and Pressures*

By F. H. BECK and M. G. FONTANA

Introduction

TEMPERATURE is one of the most important single factors influencing corrosion in a corrosive environment. Development of new chemical processes and the demand for more efficient production often requires increasingly higher operating temperatures and pressures in the chemical and other industries. Many of these advancements in industry are hampered by the lack of practical and fundamental information concerning the corrosion properties of construction materials. With this in mind the Alloy Casting Institute instigated a program to study the corrosion of commercial grades of corrosion resistant castings at elevated temperatures and pressures to determine under what conditions a given alloy will give satisfactory service. Preliminary data indicate that in many cases the more common alloys are not suitable and the use of inhibitors or new alloys will be required for particular systems. Before venturing into a long range alloy development program it was considered desirable to investigate thoroughly each commercial alloy and present the data in a convenient and useful form. The purpose of this paper is to show some of the information obtained thus far. A streamlined method of plotting data is used in a few cases where the results are relatively reliable and complete. For the purpose of making these charts of greatest value, corrosion data obtained at atmospheric pressure and lower temperatures are included.

Procedure and Apparatus

Autoclaves

One of the major problems encountered in the corrosion studies at elevated temperatures and pressures was the design and construction of autoclaves and auxiliary equipment for handling corrosive solutions. Because of the highly corrosive nature of many of these solutions and their vapors it was necessary to provide some means of protection for the test units or autoclaves. This protection was required in order to increase the service life of the autoclaves and to minimize contamination of the test solutions from corrosion products resulting from attack on the wall of the test units.

Figures 1 and 2 are photographs of two experimental autoclaves used in these studies. The functions of the various parts are indicated by these exploded views. Both units are one-quarter liter capacity and are similar in design, the only difference being the type of liners used and the lid adaptations for either pressure or temperature measurements.

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Abstract

Recent trends in the chemical industry are in the direction of higher temperatures and pressures. Few data are available in the literature on corrosion of metals and alloys at temperatures above the atmospheric boiling points of the solutions. This paper presents data on the corrosion of a variety of metals and alloys by nitric, phosphoric, acetic acids and sodium hydroxide at temperatures up to 425 degrees F. The metals and alloys include CF-8, CF-8M, CN-7MCu, CB-30, cast titanium and high silicon iron.

In general, corrosion increases rapidly as the temperature is raised above boiling and in some cases very rapid and previously unexpected attack occurs. Some data at lower temperatures are included for comparison.

Data are also presented on the inhibiting effects of metallic ions in solution and in some cases spectacular decreases in corrosion rates are observed. An example is the effect of copper ion on corrosion of stainless steel by phosphoric acid. Sub-surface corrosion of stainless steel by hot caustic is described. Borderline passivity effects in hot acids are dicussed. Equipment for conducting corrosion tests at elevated temperatures and pressures is described.

The unit in Figure 1 is fitted with a thermocouple well for measuring the temperature of the test solution and the unit in Figure 2 is equipped with a pressure gage. The autoclave in Figure 1 contains a Pyrex glass liner for holding the test solution and for protecting the autoclave body. A Pyrex sleeve provides protection to the thermocouple well. A disc cut from Teflon sheet serves as a gasket for both the autoclave body and the thermocouple well which is screwed into the bottom of the cover plate or lid. A carbon steel ring fits over the cover plate and acts

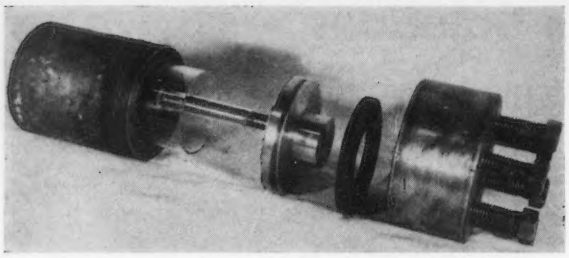

Figure 1—Exploded view of ¼-liter experimental autoclave with Pyrex glass liner.

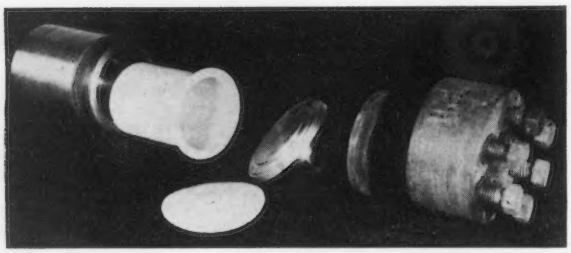

Figure 2—Experimental ¼-liter autoclave with Teflon liner.

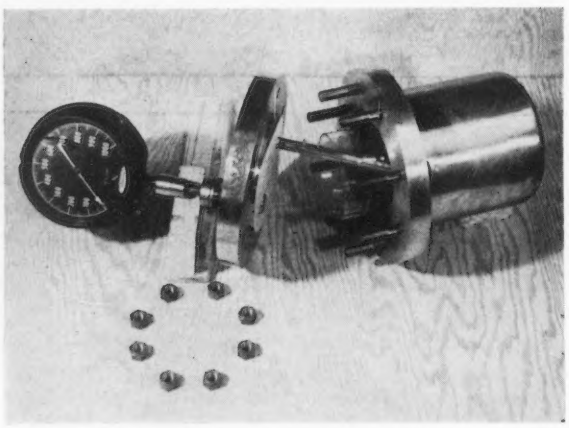

Figure 3—Exploded view of 3-liter experimental autoclave with glass liner and Teflon cover sheet and gasket.

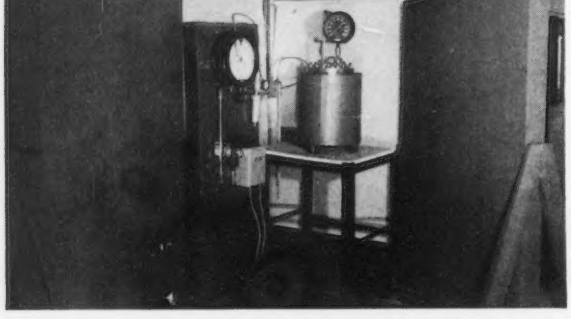

Figure 4—Assembled view of 3-liter experimental autoclave and auxiliary equipment including barricades.

as a cushion against which the bolts are screwed once the head (also of carbon steel) is screwed into place. The autoclave in Figure 2 is equipped with a Teflon liner which is machined from a solid bar and is designed with a flanged top for gasketing. This arrangement provides complete protection to the body of the autoclave. Although slight modifications in design are being made on some new autoclaves, they are essentially as illustrated in Figure 2.

Figure 3 is an exploded view of a 3-liter capacity autoclave equipped with a Pyrex glass liner and thermocouple well protection sleeve. A Teflon disc is used to protect the autoclave lid and to provide gasketing for the fittings and closure. The pressure tube to the gage contains a Teflon diaphragm for activating the gage and for protection of the gage. The autoclave body and lid are cast from alloy CN-7MCu (see Table I for compositions of alloys).

Figure 4 is an assembled view of the 3-liter autoclave and control equipment. The autoclave is immersed in a bath which is heated by a 2000-watt electric heater. Exhaust hoods and barricades provide protection to the operator.

Figure 5 includes some exploded and assembled views of several 1-liter autoclaves. These units are cast from either CN-7MCu or CF-8M alloys. Figure 6 shows the 3-liter and the 1-liter units in operating position. Four 1-liter units are heated in a single bath and thus require only one unit to be equipped for temperature measurements. The temperature is maintained by means of a thermocouple placed in the heating bath and suitable controlling equipment. The actual test temperature is measured by thermocouples which are placed in the thermocouple wells of the autoclaves. Small stainless steel tubes carry the lead wires to the instrument panel which contains the temperature recording and controlling equipment. Pressure measurements are made by means of Bourdon tube type pressure gages. The pressure gages are connected to the autoclave by means of heavy stainless steel tubes or pressure lines. Loops in the pressure lines on the gage ends maintain sufficient head to support suitable liquids in the pressure gages and thus protect the gages from corrosion. Valves and pressure connections for releasing or applying pressures are provided for on the autoclave sides of the loops. A front view of the instrument panel is illustrated in Figure 7. The barricades are in operating position.

TABLE I—Compositions of Metals and Alloys

Metal or Alloy Designation	PERCENT ELEMENT									
	Cr	Ni	Mo	Si	C	Cu	Mn	S	N	Fe
CF-8	19.28	9.65	nil	1.52	0.068	nil	0.67	0.013	0.033	bal.
CF-8M	19.60	10.30	2.53	1.50	0.067	.....	0.78	0.016	0.031	bal.
CB-30	18.1	0.10	.....	1.0	0.18	.....	0.72	.....	0.052	bal.
CN-7MCu*	20	29.7	2.62	1.15	0.055	3.84	0.39	.....	.....	bal.
High Silicon Iron†	.....	.....	.....	14.5	0.85	.....	.....	.....	.....	bal.
Titanium	Approximately 99.8 percent Ti, 0.02 percent W (Cast ingot prepared in arc furnace)									

* This Alloy Casting Institute designation covers alloys containing 18 to 22 percent Cr, 21-31 percent Ni, 0.07 percent C max. and varying amounts of Si, Mo and Cu. There are several proprietary alloys that fall within this composition range. The composition listed in the above table is for one of these alloys known as Durimet 20. All tests included in this paper for CN-7MCu were made on this alloy. This does not mean that all CN-7MCu alloys will show the same corrosion resistance.

† All tests made on Duriron.

Specimen Preparation and Corrosion Testing

Corrosion specimens approximately 1-inch x 0.5-inch x 0.25-inch, were prepared from castings of various commercial and experimental alloys. CF-8, CF-8M and CN-7MCu alloys were all tested in the quench-annealed condition (approximately 1950 degrees F and water quench). The corrosion specimens were final polished on grit No. 120 emery cloth and degreased in acetone prior to testing; 150 to 200 ml of test solution per square inch of specimen area was used. Corrosion rates were determined from weight loss data and are reported in mils penetration per year. Test periods in the autoclaves were approximately eight or 20 hours' duration and each point in the tables or curves represents a figure averaging several duplicate tests. Corrosion tests at atmospheric pressure were conducted in wide mouth Erlenmyer flasks (1000 ml capacity) equipped with finger type condensers. Reported corrosion rates are in some cases averages of five 48-hour test periods. Atmospheric pressure data are for the most part obtained from the literature and are presented to make the corrosion picture more complete and for comparison with the data at elevated temperatures and pressures.

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Results and Discussion

Nitric Acid

Surprisingly high corrosion rates were encountered for the stainless steels in nitric acid at slightly elevated temperatures and pressures. Figure 8 shows that practically a straight line relationship exists on the plot of temperature and corrosion rate. Test periods of eight hours were used with the specimens in closed autoclaves which maintained equilibrium pressure for given temperatures. Other tests in which the corrosion periods were varied from four to 24 hours showed the rate of attack to be constant.

Each curve in Figure 8 is identified with the material tested and weight percent of the test solution. The CF-8* (low carbon, 19% Cr, 9% Ni) data in 5, 20 and 65 percent nitric acid show a marked increase in corrosion rate with increasing acid concentration and temperature. The autoclave test results indicate that titanium will resist corrosion at temperatures in excess of the 345 degrees F temperature used in the studies. High silicon iron loses some of its corrosion resistance in hot dilute nitric acid and shows appreciable rates in dilute acid at temperatures above the boiling point. Poor resistance to thermal shock and brittleness of this alloy prevents its use in applications involving elevated temperatures and pressures and the present high cost and limited supply precludes use of titanium except for special cases. Other tests indicate that zirconium might also be suitable but this metal is also expensive. The improved resistance of the CF-8 and CN-7MCu alloys over the CB-30 (18% Cr) alloy indicates that nickel is beneficial in improving the corrosion resistance of stainless steels at elevated temperatures.

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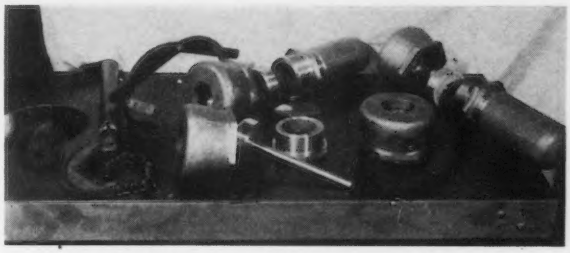


Figure 5—Assembled and exploded views of experimental 1-liter autoclave. Wrench, working table and tongs for assembling and handling autoclaves.

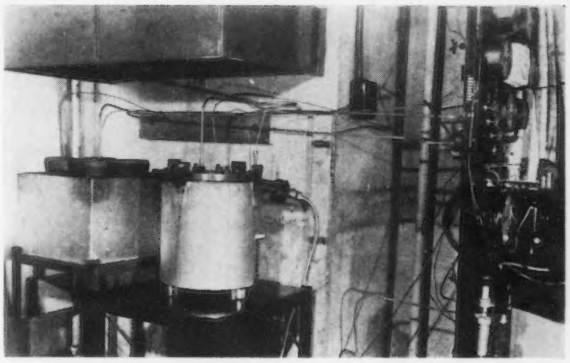
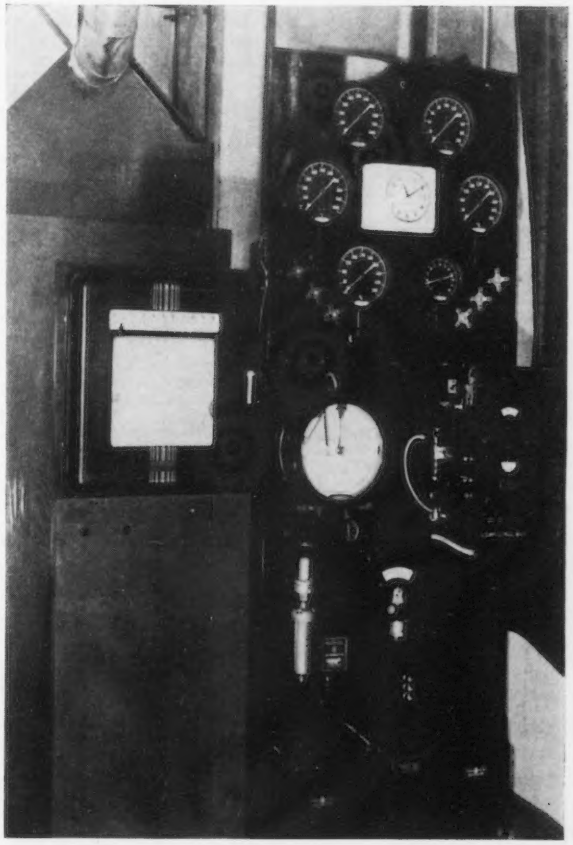


Figure 6—Experimental autoclaves with temperature and pressure control equipment. Barricades removed.



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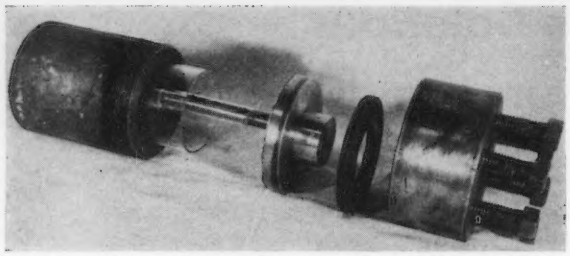

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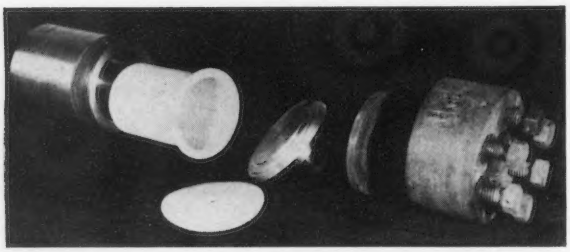

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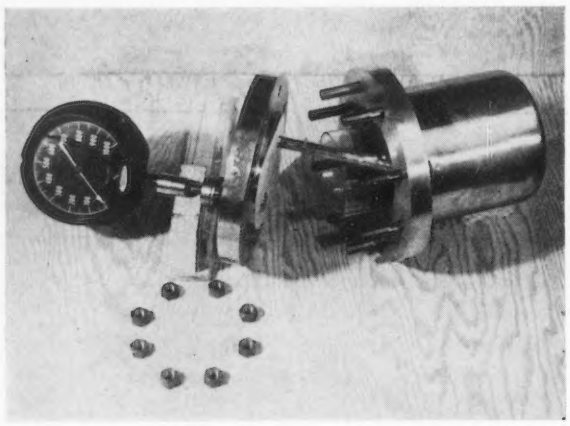

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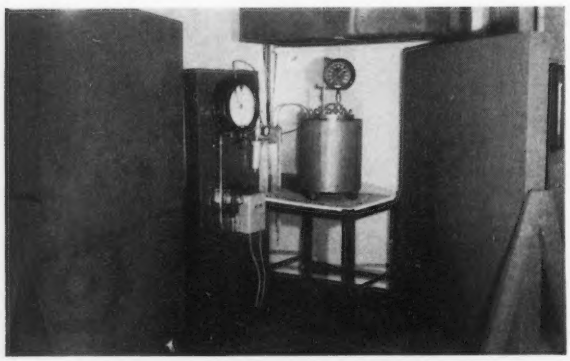

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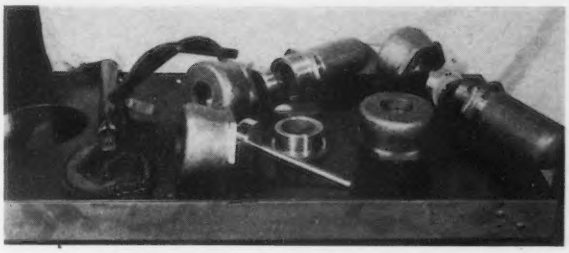

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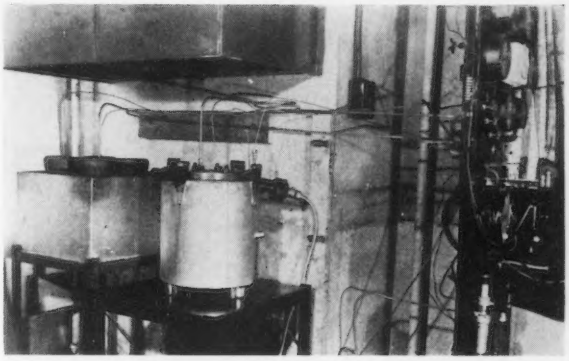

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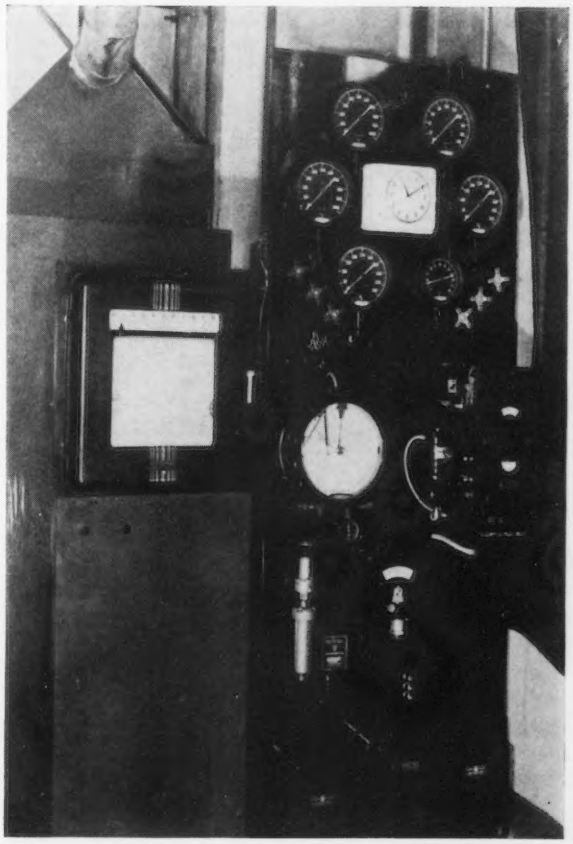

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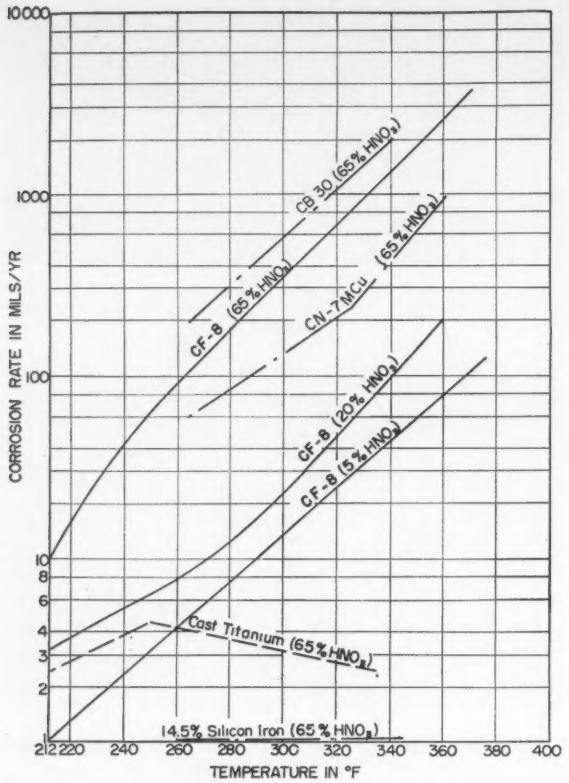


Figure 8—Corrosion of some cast metals and alloys by nitric acid, CB-30 (20 Cr, 2 Ni, 0.30 C); CF-8 (19 Cr, 9 Ni, 0.08 C); CN-7MCu* (20 Cr, 29 Ni, 2.5 Mo, 3.5 Cu, 0.07 C).*

***See footnote in Table I.**

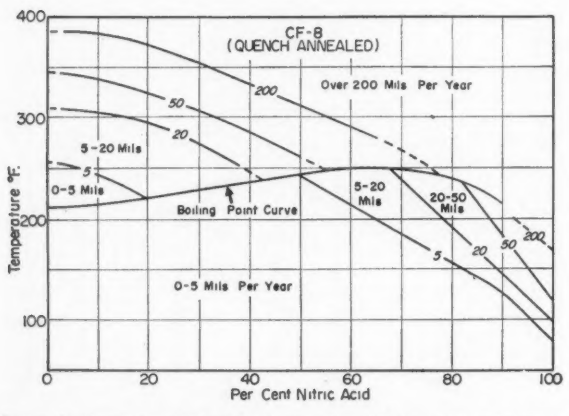


Figure 9—Corrosion of Type CF-8 cast alloy (19 Cr, 9 Ni, 0.08 C) by nitric acid as a function of temperature.

A streamlined and condensed summary of available data on the corrosion of CF-8 by nitric acid as a function of temperature is shown as Figure 9. The lines in this figure are iso-corrosion lines and they delineate regions wherein corrosion rates of less than 5 mils, between 5 and 20 mils, etc., would be expected. The atmospheric pressure boiling point curve is shown for reference purposes. The curves at the right and below atmospheric boiling are for tests conducted at atmospheric pressure. The curves at the left and above atmospheric boiling temperatures are for tests conducted in closed autoclaves where the equilibrium pressure for the corresponding temperature is developed. This method of plotting shows at a glance the performance to be expected of an alloy at any temperature or acid concentration. For example, CF-8 has exceptional resistance to all concentrations of nitric acid at all temperatures up to and including the boiling point except for hot acids of very high concentrations and fuming acid much over 100 degrees F. At temperatures above the normal boiling point the corrosion rate increases rapidly with acid concentration. Similar charts are being constructed for other materials and other corrosive media.

From comparison of the two sets of data at identical temperatures and acid concentrations, 50 and 65 percent acid at the boiling temperature, it is seen that higher corrosion rates are developed for the autoclave specimens. It is known that nitric acid decomposes to form nitrous acid and oxides of nitrogen.[1,2] Nitrous acid is very unstable but will build up an equilibrium concentration in the nitric acid when the acid is confined in pressure systems such as the autoclaves used in this study. It is believed that the nitrous acid is responsible for at least part of the increased corrosion in the autoclave tests as compared to tests conducted at atmospheric pressure. This belief is substantiated by marked reductions in corrosion rates of the autoclave specimens when urea is added to the nitric acid or when oxygen pressure is applied. Both of these methods tend to eliminate nitrous acid from the system; urea reacts with nitrous acid to form water, carbon dioxide and nitrogen; oxygen oxidizes the nitrous acid to nitric acid. Applied pressures of argon, hydrogen or nitrogen have little effect on the corrosion rate. A better knowledge of the properties of nitric acid and the decomposition products of nitric acid would be of great value in studying the inhibitor problem or in designing a special alloy for elevated temperature and pressure applications.

Corrosion charts for high silicon iron and titanium are shown as Figures 10 and 11. The symbols in Figure 10 and subsequent figures represent the following corrosion rates:

Symbol	Corrosion Rate in Mils Penetration Per Year
●	0 - 5
○	5 - 20
□	20 - 50
△	50 - 200
×	200 - and over

Except for changes in symbols and corrosion rate ranges, this method of presenting corrosion data is identical to the method developed by George A. Nelson of the Shell Development Company.

The boiling point curve at atmospheric pressure is shown in the left chart (pressure or autoclave tests) for reference purposes only.

High silicon iron shows excellent resistance to nitric acid at all temperatures and concentrations except for dilute acid where some attack occurs just below boiling at atmospheric pressure and consider-

able attack at the higher temperatures and pressures. Titanium shows excellent corrosion resistance even at the higher temperatures as shown in Figure 11.

The above tests indicate the need for alloy development and inhibitor studies for applications involving very strong nitric acids or nitric acid at elevated temperatures and pressures. Preliminary studies made along these lines on CF-8 and CF-8M show some promise of mitigating corrosion by the use of inhibitors.

Phosphoric Acid

The austenitic stainless steels are, in general, quite resistant to phosphoric acid in all concentrations up to 50 percent acid by weight and at all temperatures up to and including the normal boiling point of the acid. Above 50 percent acid concentration these alloys in many cases lose their corrosion resistance. This is particularly true for specimens exposed to boiling acids as illustrated in the atmospheric pressure tests in Figure 12 for CF-8. Alloy CF-8M performs better than the plain CF-8 alloy at the higher acid concentrations, but is also vulnerable to the more concentrated acids at the higher temperatures as shown in Figure 13. CN-7MCu type alloys are more resistant than the CF-8M alloy, but are not sufficiently resistant to fill the gap for the very strong acids near the boiling points. Figure 14 shows corrosion of CN-7MCu by phosphoric acid.

The data for the pressure tests show again, as in the case of CF-8 in nitric acid, the pronounced effect of temperature and pressure on corrosion. Of the alloys tested, CF-8 was most affected by the acid at increased temperature and pressure. While alloy CF-8M showed a rapid increase in rate at temperatures above the normal boiling point of the acid, relatively low rates were encountered at the boiling point. The CN-7MCu alloy performed somewhat better than CF-8M.

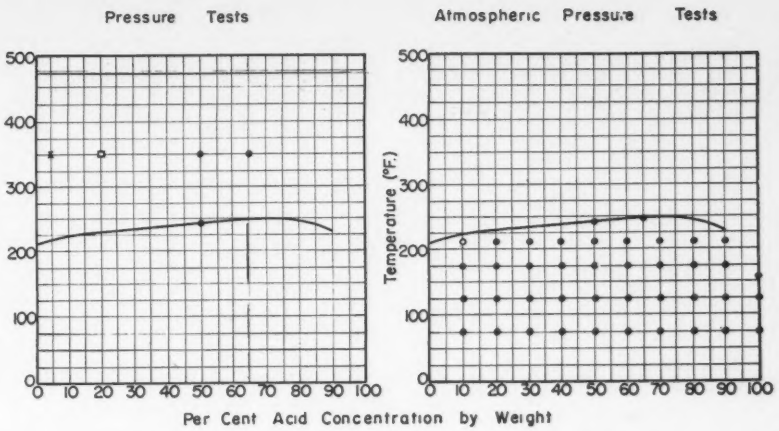


Figure 10—Corrosion of 14.5% silicon iron cast alloy by nitric acid.

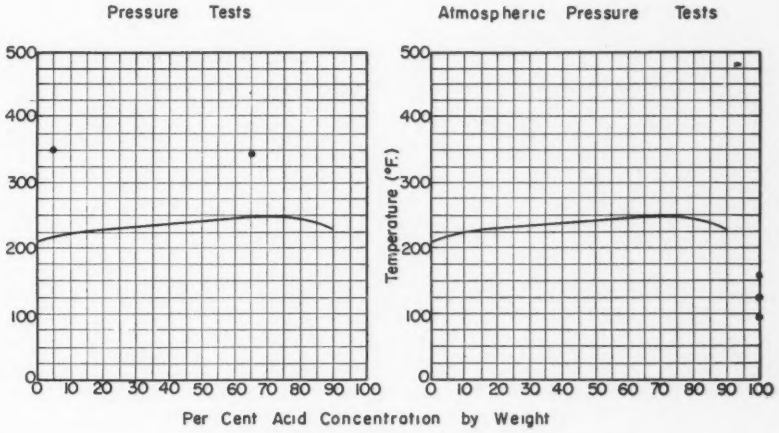


Figure 11—Corrosion of cast titanium by nitric acid.

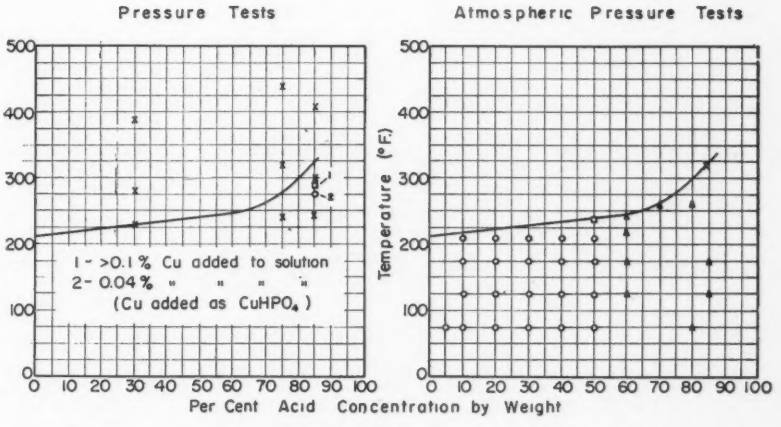

Pressure Tests
Atmospheric Pressure Tests
1 - >0.1 % Cu added to solution
2 - 0.04 % " " " "
(Cu added as CuHPO4)
Temperature (°F.)
Per Cent Acid Concentration by Weight

Figure 12—Corrosion of Type CF-8 cast alloy (19 Cr, 9 Ni, 0.08 C) by phosphoric acid.

Inhibitor studies are in progress at present to extend the usefulness of the less expensive alloys. Figures 12 and 15 indicate that the addition of copper ions as $CuHPO_4$ to phosphoric acid is effective in reducing the corrosion of the CF-8 alloy. The corrosion rate of CF-8 is reduced from 10,000 to 10 mils per year by the addition of 0.03 percent copper to 85 percent acid at 270 degrees F. These are only preliminary results and a considerable amount of testing must be done to extend these data. The inhibiting effect of copper is believed to result from a complex copper ion and the general trend of the curves would indicate an anodic inhibitor. Note the

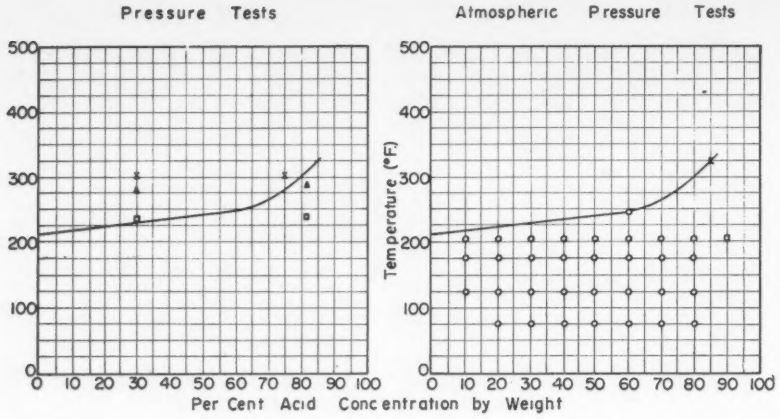


Figure 13—Corrosion of Type CF-8M cast alloy (19 Cr, 11 Ni, 2.5 Mo, 0.08 C) by phosphoric acid.

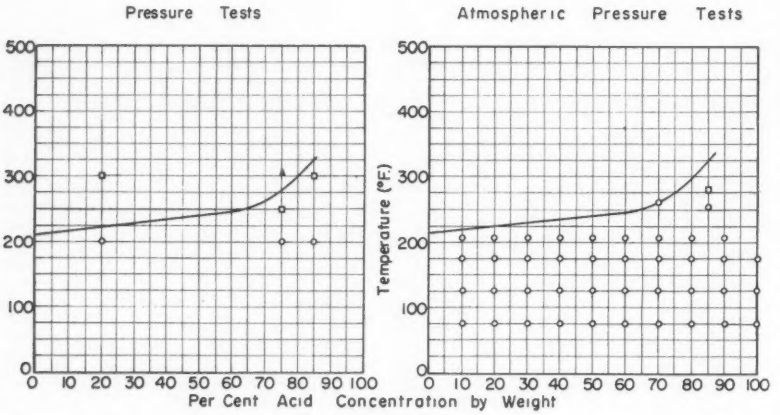


Figure 14—Corrosion of Type CN-7MCu cast alloy (20 Cr, 29 Ni, 2.5 Mo, 3.5 Cu, 0.07 C) by phosphoric acid.

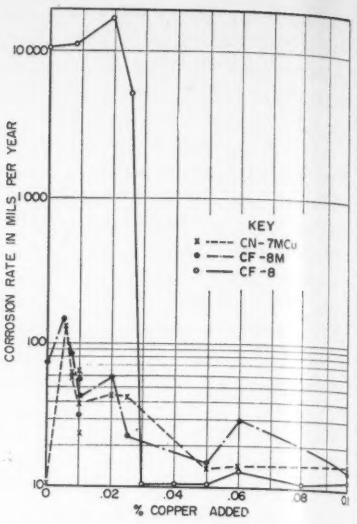


Figure 15—Effect of copper ion on corrosion by 85% phosphoric acid at 270°F. CN-7MCu (20 Cr, 29 Ni, 2.5 Mo, 3.5 Cu, 0.07 C); CF-8M (19 Cr, 11 Ni, 2.5 Mo, 0.08 C); CF-8 19 Cr, 9 Ni, 0.08 C).

increase in rate for all three alloys at the lower concentrations of copper; CN-7MCu alloy corrodes very little when copper is absent from the solution.

Acetic Acid

The CF-8 type cast alloys are quite resistant to acetic acid of all concentrations and temperatures up to the normal boiling point of the acid. At the boiling temperature the CF-8 alloy exhibits borderline passivity. This is more pronounced at the higher acid concentrations and in very strong acids the phenomenon operates at temperatures somewhat below the boiling point of the acid. Alloys CF-8M and CN-7MCu are resistant to all concentrations at all temperatures up to and including the boiling point.

At temperatures above the normal boiling point the CF-8 alloy becomes quite active, especially in glacial acid. Corrosion rates may vary anywhere

TABLE II
Corrosion of Type CF-8 Cast Alloy by Acetic Acid
(19.3 Cr, 9.7 Ni, 0.07 C)

TEMPERATURE °F	CORROSION RATE IN MILS PER YEAR		
	Glacial Acetic	75 Percent Acetic	30 Percent Acetic
230	65	....	<1
245	90	....	....
245	4	....	....
250	1	....	....
270	220	....	7
285	6	6	....
310	70	....	....
310	17	....	....
320	1	....	....
325	....	....	0
330	....	....	10
350	690	....	4
350	....	....	140
355	80	860	....
360	390	....	....
360	70	....	....
370	....	....	160
370	....	....	2
395	....	....	1000
395	....	....	30
400	260	....	200
400	20	....	120

TABLE III
Corrosion of Type CF-8M Cast Alloy by Acetic Acid
(19.6 Cr, 10.3 Ni, 0.07 C, 2.5 Mo)

TEMPERATURE °F	Glacial Acetic	75 Percent Acetic	30 Percent Acetic
230	13	....	1
230	<1	....	....
330	....	....	3
330	....	....	0
340	40	1	....
340	0	....	....
350	0	....	20
350	....	....	1
370	....	....	210
370	....	....	2
395	30	....	....
395	7	7	....
400	20	....	....
400	0	....	....

between a few mils per year and several hundred mils per year at temperatures only slightly above the boiling point as is indicated in Table II. CF-8M is much more resistant and shows a much stronger tendency for becoming passive as shown by the data in Table III. In glacial acetic acid at 400 degrees F, CF-8M may exhibit corrosion rates ranging from zero to approximately 30 mils per year. Data at other concentrations and temperatures are too scattered for discussion at this time. Future tests will be directed toward data of the type suitable for showing the ranges of corrosion rates as illustrated in Figure 9.

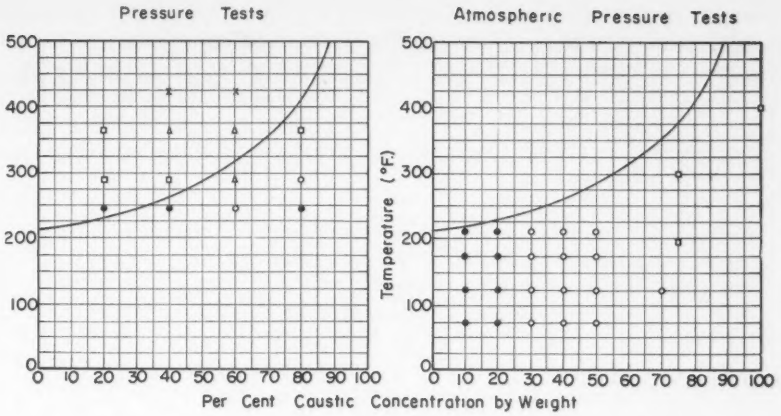


Figure 16—Corrosion of Type CF-8 cast alloy (19 Cr, 9 Ni, 0.08 C) by sodium hydroxide.

Sodium Hydroxide

The CF-8 stainless steels are resistant to sodium hydroxide of all concentrations below 50 percent by weight at all temperatures up to the boiling point. As the caustic concentration is increased over 50 percent, the CF-8 alloy shows a decrease in corrosion resistance. Alloys CF-8 and CF-8M both exhibit increasing corrosion rates with increasing temperature. The CN-7MCu alloy is much superior to the CF-8 type alloys in all concentrations of caustic particularly in the concentrated solutions at the higher temperature, 200-300 degrees F and higher.

Tests at temperatures slightly above the normal boiling points of aqueous sodium hydroxide solutions show substantial increases in corrosion rates for the CF-8, CF-8M and CN-7MCu alloys. Figure 16 is a summary of the data observed for the CF-8 alloy and is typical also of the CF-8M alloy. Note that the intermediate concentrations of caustic, 40 and 60 percent, are more corrosive than the 20 and 80 percent concentrations at similar temperatures. Both the CF-8 and CF-8M alloys showed severe undercutting or sub-surface corrosion in 40 and 60 percent caustic at 425 degrees F. This effect was noted to a lesser extent at 360 degrees F in the same concentrations of caustic. Specimens displaying this "sub-surface" corrosion maintained bright surface films of metal which could be peeled off to reveal a layer of corrosion product. Longer exposure times, in excess of the 20-hour test periods used in these studies, would probably destroy the surface film.

Preliminary tests on CN-7MCu show that this alloy is very resistant to 20 and 40 percent caustic at temperatures up to 350 degrees F, which were the most severe tests made.

Acknowledgment

This investigation was made in the Corrosion Research Laboratories, Engineering Experiment Station, under contract between the Alloy Casting Institute, 32 Third Avenue, Mineola, New York, and The Ohio State University Research Foundation, Columbus, Ohio. The interest and support of the ACI members and the Corrosion Steering Committee of the ACI, and permission to publish the data, are gratefully acknowledged.

Much of the corrosion testing at elevated temperatures and pressures was performed by Bruce W. Dunnington, Admiral A. Watts and George W. Zuspan.

References

1. U. R. Evans. Behavior of Metals in Nitric Acid, *Trans. Faraday Society*, **40**, 120-130 (1944).
2. W. M. Latimer. Oxidation Potentials, Prentice-Hall, Inc., 1938, p. 83-95.

Discussions

Magnetic Amplifier Controls for Rectifier Protecting Underground Metallic Structures Cathodically. By Oliver Henderson. CORROSION, Vol. 9, No. 7, 216-220 (1953) July.

Discussion by Daniel R. Werner, American Telephone and Telegraph Co., Kansas City, Mo.

Mr. Henderson indicates in his paper that the amplifier was designed to give a power amplification of 12,000. The power to activate the amplifier is obtained from the changes in the potential between the cable and the waterpipe. These changes in potential are caused by changes in the load on the electric railway system and these changes occur at various rates. It is indicated that a potential change of 0.2 volt cable-to-waterpipe (the waterpipe-to-earth potential variation is small as compared to the cable-to-earth potential variation) is sufficient to swing the amplifier from its minimum output to its maximum output.

Magnetic amplifiers do not have an instantaneous response time as far as the input and output is concerned and the power gain of 12,000 is possible only if the potential change of 0.2 volt is sustained for a time period of about one second. If the potential changed 0.2 volt instantaneously and the potential was sustained, the cable-to-earth potential would become positive for a part of a second until the amplifier would have time to react and the output current increase sufficiently to make the cable negative with respect to earth. The rate of change of the railway currents in the installation made by Mr. Henderson was apparently slow enough so that no positive cable-to-earth potential flashes occurred or they were not picked up by the recording meter (the recording meter used sampled the cable-to-earth potential at 5-second intervals).

For those interested in design the following information will be of value. Suppose that the structure-to-earth potential is a maximum of +1.0 volt without drainage and 11 amperes is required to make the structure-to-earth potential —0.1 volt. With no stray current the minimum output of the magnetic amplifier would be set at 1.0 ampere and the structure-to-earth potential would be —0.1 volt. Suppose stray current now starts and increases to its maximum value at a certain rate. It is desired that the structure-to-earth potential never becomes positive to earth. A potential change of 0.1 volt in the structure-to-earth potential can thus be allowed. If positive structure-to-earth potentials are to be avoided the power delivered to the input of the amplifier while the structure-to-earth potential is changing from —0.1 to zero must be sufficient to swing the output of the magnetic amplifier from 1 ampere to 11 amperes in the time interval it takes for the stray current effect to increase to its maximum value. It will thus be seen that the potential change of 0.1 volt and not 1.1 volts must be used in designing the amplifier system. The above discussion and Mr. Henderson's paper assumes that the reference electrode to make contact with the earth is the same material as the structure itself.

Reply by Oliver Henderson:

It is true that the high gain of the magnetic amplifier is achieved somewhat at the expense of response time, which is however on the order of only a very few seconds. Since most of the important fluctuations in cable-to-earth potential have periods of 15 minutes or more, a delay of one or two seconds on the part of the rectifier control is inconsequential.

Kel-F Applications in Corrosive Systems. By L. C. Rubin and W. O. Teeters. CORROSION, Vol. 9, No. 3, 100-102 (1953) Mar.

Question by Robert P. Lee, National Lead Co., Titanium Div., South Amboy, N. J.:

In liquid $TiCl_4$ handling, up to 278 degrees F, we have used both Kel-F and plasticized Kel-F sheet material with success. Early Kel-F oils, however, were soluble in cold $TiCl_4$ liquid. Have you any new developments in oils or greases which have enhanced corrosion resistance in this medium?

Reply by L. C. Rubin and W. O. Teeters:

No new formulations of oil and greases are available yet.

Question by Gustave Heinemann, Columbia-Southern Chemical Corp., Corpus Christi, Texas:

Can you give us any information regarding the permeability of gaseous chlorine to Kel-F coatings or diaphragm formulations?

Reply by L. C. Rubin and W. O. Teeters:

Chlorine does diffuse through both plasticized and unplasticized Kel-F. However, there is no chemical reaction between the Kel-F and the chlorine.

Question by William G. Ashbaugh, 3218 Ave. O½, Galveston, Texas:

1. In your table which showed the resistance of Kel-F to various chemicals you noted the results as being "no effect." By what means did you measure the resistance of the plastic, by weight or volume or mechanical measurements?

2. What is the maximum temperature at which Kel-F can be used?

Reply by L. C. Rubin and W. O. Teeters:

1. "No effect" was determined by there being no evidence of attack on the carbon steel.

2. Under suitable conditions, unplasticized Kel-F can be used at temperatures as high as 190 degrees C. Plasticized material has been used satisfactorily in some applications as high as 150 degrees C.

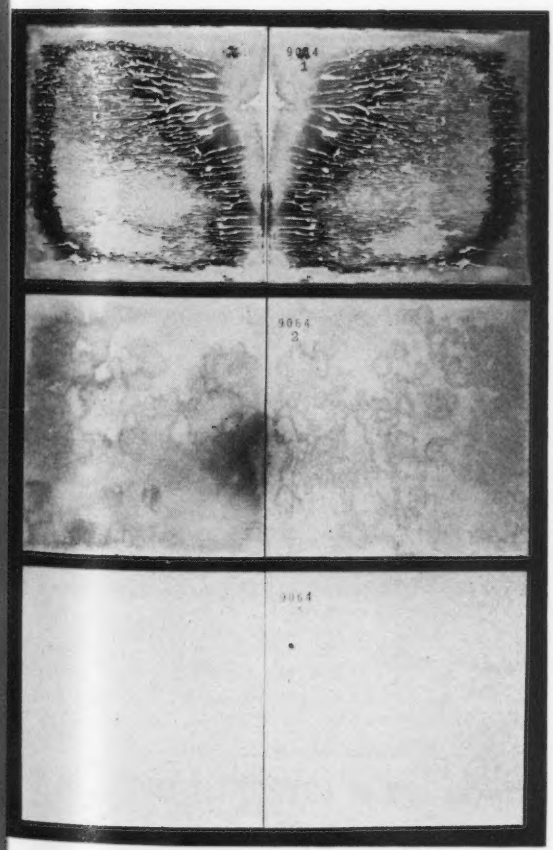
Effects of Polarization on Telephone Cable Buried Through a Salt Bed. By Daniel R. Werner. CORROSION, Vol. 9, No. 7, 232-236 (1953) July.

Remarks by R. L. Rayner, Michigan Bell Telephone Co., Detroit, Mich.:

Appendix A of this paper which presents a null method of measuring current flow along a cable sheath is of special interest. It is simpler than the method now generally in use which requires determining the resistance of the cable sheath between test points from tables.

Discussion by Daniel R. Werner:

There are some types of cable which are designed to be buried in the ground which have coverings of steel tapes or galvanized armor wires and in addition the types of cable known as tape armored or wire armored cable have a cushion of jute between the lead sheath and the steel tape or armor wires. As the coverings are applied over the lead sheath in the manufacturing process all layers of jute, steel tape or armor wires are placed around the lead sheath under a flow of hot asphalt. The latest type of steel tape covered buried cable does not have the jute cushion but alternate layers of lead tape and paper tape instead for lightning protection reasons. On these types of cables the wires which are used in connection with obtaining the millivolt drop along the cable are soldered, for construction reasons, only to the outside steel tapes or armor wires. Tests have indicated that the resulting resistance of the steel tapes or armor wires over the thirty foot section bridged by the test leads is not a constant quantity and must be determined by field tests for each test location. For this reason the null method outlined in Appendix A has been found to be the most practicable method of quickly determining the amount of current flowing.



A TECHNICAL NOTE

Inhibited Interleaving Tissue Prevents Water Staining Of Aluminum

Addition of 1.5 to 3 percent sodium chromate by dry weight to tissue paper used for interleaving aluminum sheets packed unoiled effectively controls water staining, experiments by C. C. Lacy and E. W. Everhart of the Kaiser Aluminum and Chemical Corporation Division of Metallurgical Research show.

Water staining has been a particular problem of the aircraft industry where quantities of aluminum sheets are stored. While discoloration of the surface is important from the standpoint of appearance. Kaiser's investigations did not indicate it significantly affected the strength of the material. Alloys tested were 3S and 24S-F.

The development is protected by patents.

Figure 1—Panels from test packs exposed to a 30-day high humidity test. Top—No interleaving tissue. Center—Interleaved with untreated tissue. Bottom—Interleaved with tissue impregnated with inhibitor.

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HOUSTON **1061 M & M Building** **TEXAS**

Topic of the Month

Plastic Piping for Electrical Conduit In Corrosive Atmospheres

By R. W. FLOURNOY*

THE USE OF plastic materials for tanks, piping systems and ductwork has increased rapidly during the past few years. Furthermore, because of the corrosion of metal electrical conduit in corrosive atmospheres a new field for the use of plastic piping has developed. Plastic has many advantages and some disadvantages when used for electrical conduit compared to metal conduit.

Corrosion resistance of rigid polyvinyl, styrene copolymers and glass fiber reinforced polyester plastics is excellent for many corrosive environments and molded pipe and fittings are available in several of these plastic materials which can be used as conduit. Plastic conduit can be bent by heating to 200-225 degrees F in the case of rigid polyvinyl and styrene copolymers and weighs about one-fourth as much as comparable steel, making handling and installation easier. Also, the smooth surface of the interior of plastic piping makes drawing electrical wiring through it relatively easy. The conduit does not require regular maintenance by exterior painting and its service is generally satisfactory.

The usual limitations of plastic materials apply to plastic conduit. Structural strength is lower than that of steel and it requires support approximately every four feet and even when so supported tends to sag slightly.

Finding corrosion resistant supports and outlet boxes for plastic piping is a problem although molded thermosetting phenolic outlet boxes and certain other fixtures are available.

It is relatively easy to thread piping for joints but the threaded joints are subject to notch sensitivity and to fracture.

Rigid polyvinyl and a fire resistant grade of styrene copolymer are available. Polyester plastics are inflammable. The question of fire resistance may cause difficulty in negotiations for insurance and underwriters' approval.

For over a year a plastic conduit system has been in service in one plant. The installation has been so satisfactory that additional plastic conduit is being added to replace metal conduit as it fails in the corrosive industrial atmosphere in this plant. Sulfur dioxide and hydrochloric acid fumes cause ordinary metal to fail after exposure of from a few months to a year.

Plastic piping has proved in this instance, at least, a means of successfully solving a long-standing corrosion problem.

Figure 1—Corroded steel conduit and fixtures in a corrosive industrial atmosphere.

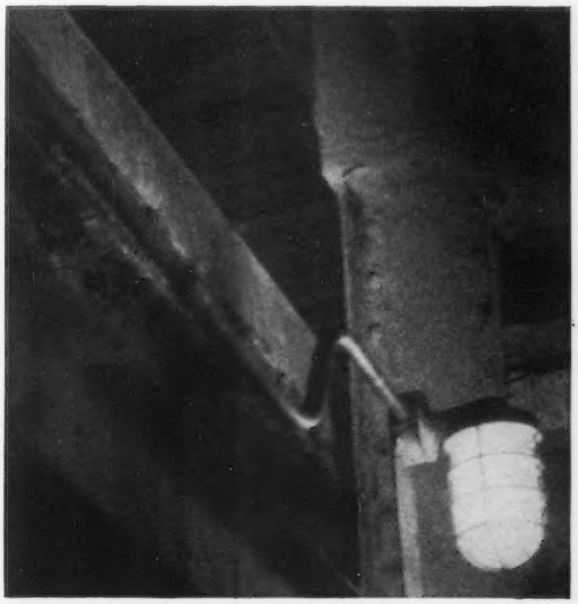

Figure 2—Rigid polyvinyl chloride conduit and coated electrical fixture replacing steel conduit.

* Corn Products Refining Co., Argo, Ill.

NACE News

Corrosion Session Held for Foreign Scientists

Chicago Officers

Chicago Section NACE has elected new officers. L. W. Ewing, Standard Oil Company of Indiana was elected chairman; R. I. Lindberg, Sinclair Research Laboratories, Inc., was elected vice-chairman; L. W. Petersen, Swift and Co., was elected secretary; and R. W. Flournoy, Corn Products Refining Co., won the treasurer's post. The elections were held in May.

Martin Appointed

R. C. Martin of the Plantation Pipe Line Co., Atlanta, Ga., has been appointed to the NACE South East Region Board of Trustees as the representative from the Atlanta Section.

Corpus Christi Holds Largest '53 Meeting

The largest attendance in more than a year, 51 persons, marked the Corpus Christi Section June meeting. John W. Nee, Briner Paint Manufacturing Co., Corpus Christi, was on the program as a technical speaker. As part of the program, several copies of a paper, "Gasoline Resistant Tank Coatings," by W. W. Cranmer were distributed.

Program Preference Survey blanks have been distributed to section members so programs with the widest appeal may be arranged. In order to gain better knowledge of the type of work section members are engaged in, each person is asked to classify his job both as to the industry and to the type of job he has. The survey blank is accompanied by a stamped envelope, addressed to R. H. Pfrehm, section secretary-treasurer.

Sabine-Neches Section

The Sabine-Neches Section has elected officers for 1953-54 as follows: Charles A. Ridenour, chairman; Crawford E. Chaisson, vice-chairman and Charles E. Huddleston, Jr., secretary-treasurer. Monthly meetings have been discontinued for the summer and will be resumed in September.

Brooks Resigns

W. B. Brooks, The Dow Chemical Co., Freeport, Tex. has resigned as Corrosion magazine correspondent representing the chemical industry. Mr. Brooks has been a member of the National Association of Corrosion Engineers since 1948. Mr. Brooks also resigned as program chairman of Houston Section, because of the press of other business.

NACE MEETINGS CALENDAR

Sept.
16—Los Angeles Section.

Oct.
7—Southern New England Section.
20—Baltimore Section

Regional Meetings

Oct.
7-9—South Central Region. Mayo Hotel, Tulsa, Okla. Technical Committee meetings. Technical program on oil transportation, production and refining.

Nov.
12—South East Region. Birmingham, Ala.
19-20—Western Region. Biltmore Hotel, Los Angeles, Cal. Technical Committee meetings, Symposia on refinery and aircraft corrosion.

Bachman Resigns

P. W. Bachman, The Davison Chemical Corp., Baltimore, Md., has resigned from the Publication Committee of the National Association of Corrosion Engineers because of the lack of available time to devote to committee work. Mr. Bachman is a past Director of NACE representing active membership, and has been a member of the Publication Committee for several years. He joined NACE as an active member in 1946.

Meeting of Porcelain Enamel Institute Set

The Porcelain Enamel Institute will hold its 1953 Annual Meeting at the Greenbrier, White Sulphur Springs, W. Va., Sept. 30-Oct. 2, according to John C. Oliver, Institute Secretary.

Featured will be two general sessions: Progress For Our Industry, to be held Wednesday, Sept. 30; and, New Uses for Porcelain Enamel, to be held Thursday, Oct. 1.

The society is now receiving applications for the Research Fellowship post at the National Bureau of Standards. George A. Warren, who held the post has left for employment in private industry. The Fellowship involves close work with the Enameled Metal Section of the bureau and with various laboratories in industry. Edward Mackasek, managing director, Porcelain Enamel Institute, Inc., 1346 Connecticut Ave., N. W., Washington 6, D. C., is receiving the applications.

Technical Sessions And Plant Tours Are Arranged at Houston

Corrosion specialists from eleven foreign countries were present at a meeting July 8 at the Rice Hotel, Houston where South Central Region members of the National Association of Corrosion Engineers presented a program of corrosion. The twenty-two scientists were on a tour of the United States investigating what industry in this country is doing to combat corrosion. The tour was sponsored by the Mutual Security Agency.

The visiting scientists heard discussions by E. P. Doremus, Cathodic Protection Service, Houston on cathodic protection; by F. A. Prange of Phillips Petroleum Co., Bartlesville, Okla. on designing against corrosion in oil refineries; by H. L. Bilhartz, The Atlantic Refining Co., Dallas on oil production corrosion and by Carl Moore, Parker Rust Proof Co., Dallas and M. A. Parr, Parkerizing of Texas, Inc., who spoke on surface preparation of metals and coatings.

Plants Are Visited

The morning session at the Rice Hotel was devoted to the technical talks and comments and questions and the afternoon to tours of Houston area plants. After lunch the group went to the Mayes Bros. pipe coatings plant where Boyd Mayes conducted them through the 70-acre installation. The visitors saw a crew applying Bitumastic and kraft paper to pipe, holiday inspection; pipe coated with concrete for negative buoyancy, coating being removed from old pipe for reconditioning and reuse.

At Tube-Kote, Inc., plant Larry Heinen conducted the group through the coating plant. The engineers saw all the operations involved in this firm's process from the unloading of the new pipe to the inspection of the coating on the inside.

Walter F. Rogers Presides

Walter F. Rogers, of Gulf Oil Corp., NACE president, presided at the morning session. Following a short welcoming address, members of NACE present were introduced to the visitors.

E. P. Doremus then gave a talk illustrated with slides on the methods and economics of cathodic protection applied to buried and submerged structures. F. A. Prange concentrated on metals used in oil refineries and covered the importance of location, process and medium in designing apparatus for refineries. H. L. Bilhartz prefaced his remarks with a short history of NACE and the NACE Technical Practices Committee No. 1. His discussion cov-

(Continued on Page 12)

Attendance Confirms Wisdom of Houston's Summer Schedule

Any misgivings officers of the Houston Section had about holding summer meetings were dispelled at the first summer meeting July 14 at Kelley's Restaurant. Attendance was above the average of most regular meetings. There were 93 guests and members present. Members heard John W. Nee of Corpus Christi speak on "New Developments in the Coatings Field."

One such new development was the use of vinyl resins in combination with alkyds. These paints are low in solids and to gain coating thickness per application, mastics are sometimes added, Mr. Nee said. Use of chlorinated rubber paints, polymer-epoxy resin combinations, silicones and various other combinations of paints were described. Sample panels of the various coatings were circulated through the audience.

One unusual use for neoprene paint, Mr. Nee cited, was the coating of wooden tanks in intermittent service. The neoprene fills the cracks between staves in the tank and even when the tank remains dry for long periods, the wood will not shrink, hence the tank will not leak when fluids are put into it. Mr. Nee illustrated his talk with slides showing engine exhaust stacks in service at temperatures close to 1000 degrees F. He also had on display, jars of raw paint materials.

Members were told of the section's campaign to get new corporate memberships for the National Association. Chairman L. G. Sharpe said the goal for the section has been set at 75. This equals the goal set for the entire NACE organization. "We believe the Houston section can attain its goal if all members will give their enthusiastic cooperation," he said.

The section was host to NACE members from other sections and areas. Present were Victor C. E. Kiang, Chinese Petroleum Corp., Kaohsiung, Formosa; Humberto Lobo, Jr., Fabricas Protexas, Monterrey, Mexico, and Frank L. Whitney, Jr., Monsanto Chemical Co., St. Louis, Mo. Mr. Whitney is chairman of the technical program committee for the 1954 conference at Kansas City.

Steam Contamination Papers Are Published

Five papers on steam contamination along with discussions presented at the 1951 American Society of Mechanical Engineers Annual Meeting under sponsorship of the Joint Research Committee on Boiler Feedwater Studies have been published under one cover. The five papers are Correlation of Silica Carry-Over and Solubility Studies, by C. Jacklin and S. R. Browar; The Spectrophotometric Determination of Small Amounts of Soluble Silica in Water to the Determination of Undissolved Forms of Silica, by H. E. Robinson, Elizabeth J. Grimm and C. Brown; Field Testing of Steam Sampling Nozzles as Applied to Evaporator Vapor by E. B. Morris and Influence of Boiler Design and Operation Conditions on Steam Contamination by P. M. Brister, F. G. Raynor and E. A. Pirsh.

NBS Corrosion-Related Publications Are Listed

Two National Bureaus of Standards publications of likely interest to some corrosion engineers are: Publication RP2394, An Interferometer Procedure Applied to the Study of the Chemical Durability of Silicates, Enamels and Metals, by Robert G. Pike and Donald Hubbard, 7 pages, ten cents; and Publication RP2395, Transitions and Phases of Polytetrafluoroethylene (Teflon), by Charles E. Weir, 3 pages, five cents. Copies may be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

George Granger Brown To Give AIChE Lecture

The fifth annual Institute Lecture of the American Institute of Chemical Engineers will be given at the annual meeting in St. Louis, Mo., Dec. 13-16 by George Granger Brown, dean of the college of engineering and Edward De Mille Campbell University Professor of Engineering at the University of Michigan, Ann Arbor, Mich. Dr. Brown's topic will be on thermodynamics, one of the fundamental basic studies underlying chemical engineering. Each lecture provides a comprehensive survey of some important aspect of chemical engineering by a prominent engineer.

FEDERATED METALS OFFERS NEW REPORT: "CATHODIC PROTECTION WITH ZINC ANODES"

Federated's Corrosion Advisory Service offers you, without obligation, a new report titled, "Cathodic Protection With Zinc Anodes," prepared by Ebasco Services Inc. for the American Zinc Institute. This new publication reports additional findings obtained since the first report was issued in November, 1951. In it you will find important and valuable facts that have influence on the proper applications of zinc anodes. Use coupon below for your free copy.

Zinc Anodes are available from Federated in standard lengths of 3 ft. and 5 ft. They are cast of Special High Grade Electrolytic Zinc in cross-sections of 2 sq. in. and 4 sq. in. Each has full length chemically-bonded steel core rod. Silver-soldered connecting wires can be attached if desired.

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Program Set for Western Region Fall Conference

Automatic Control Book

Principles of Automatic Control, a 32-page booklet presenting the fundamentals of automatic control, has been published by the Instrument Society of America. The booklet costs $1.25. The society also has published, Proceedings of the Instrument Society of America, for 1952. It consists of a complete record of the 1952 Instrument Conference and 77 technical papers and 21 abstracts. Cost of the 350-page book is $10.00 to non-members and $5.00 to members. Both may be ordered from 1319 Allegheny Ave., Pittsburgh, Pa.

Fulbright Competition

Competition for university lecturing and post-doctoral-level research under the Fulbright Awards is now underway. The positions will be open in Europe and the Near East, Japan and Pakistan. Applications for the competition must be postmarked no later than Oct. 15, 1953, to be considered. Application blanks and more information concerning the awards may be secured by writing the Conference Board of Associated Research Councils Committee on International Exchange of Persons, 2101 Constitution Ave., Washington 25, D. C.

TP Subcommittees To Meet; 2 Symposia Also Are Scheduled

Meetings of two Technical Practices Sub-Committees, addresses by prominent NACE men and two technical sessions, one on refinery corrosion and the other on aircraft corrosion problems will feature the 1953 Western Region Conference of the National Association of Corrosion Engineers to be held Nov. 19-20 at the Biltmore Hotel, Los Angeles, Cal.

H. H. Anderson, formerly NACE vice-president, Eugene H. Grizzard, and Vance N. Jenkins, the latter formerly NACE president, will make welcoming addresses. Technical Practices Sub-Committee No. 1A on Corrosion of Oil and Gas Well Equipment (Pacific Coast) and Technical Practices Sub-Committee No. 6L on Asphalt-Type Underground Protective Coatings will hold meetings.

Plans and arrangements for the Regional Conference are being completed. In order to inform NACE members living in the region, a publicity release will be mailed, probably from Los Angeles, Cal. about Aug. 15. A second mailing of programs and registration blanks will be mailed to a selected mailing list about the middle of October. It has been proposed that multiple copies of all publicity be sent to NACE Corporate members and other selected larger companies to be distributed by these firms to interested personnel and to be posted on plant bulletin boards.

Present plans are for registration to start about 9:00 am, Nov. 19. At 9:30, the two technical practices committees will meet. At 11 addresses of welcome will be made. In the afternoon, there will be three 45 minute talks. In the evening, a fellowship hour will be held.

Two half-day sessions will be held Nov. 20, one on refinery corrosion, and the other on aircraft corrosion.

Sometime during the conference, Fred M. McConnell will make a brief explanation of the benefits of NACE membership. Membership application blanks will be available. If possible, membership applications will be post-dated to Jan. 1, 1954, so applicants will have a full membership.

The conference will be preceded by the University of California at Los Angeles Corrosion Short Course, Nov. 16-18.

Nuclear Gas Turbines Predicted by Chemist

On the grounds that gas turbines are most efficient at high temperatures, Prof. Farrington Daniels, chairman of the chemistry department, University of Wisconsin, believes use of nuclear fission to power gas turbines may be feasible. To eliminate attack on turbine parts by oxygen used for combustion, an inert gas could be circulated in a closed cycle.

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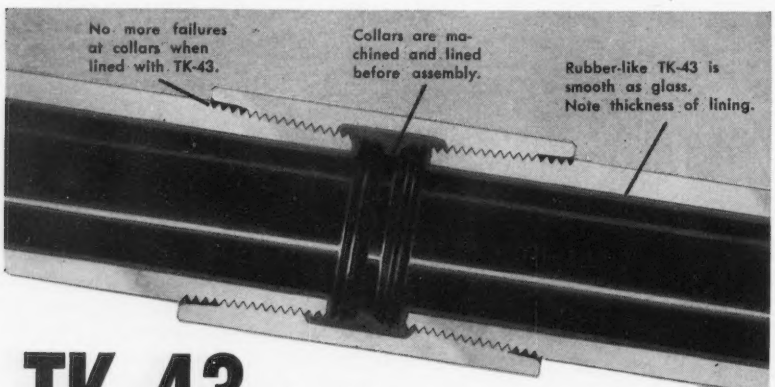
Constructive discussions on technical material published in Corrosion is welcomed.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SEND THIS COUPON NOW FOR FULL DETAILS!

Texas A & M Corrosion Short Course Is Scheduled

Fundamentals and practical aspects of corrosion will be stressed at the basic short course to be held at A & M College of Texas, College Station, Tuesday through Friday morning, September 22-25, 1953. The course will be sponsored by the South Central Region of the National Association of Corrosion Engineers and the chemical engineering department of A & M College.

In general, the following subjects will be covered: Fundamentals, materials of construction, coatings, cathodic protection, instrumentation and special topics. One feature will be small group discussion sessions. Meetings will be held in the air-conditioned Memorial Student Center on the A & M campus. There are available approximately 100 accommodations at the Student Center. Reservations for these rooms will be accepted in order of receipt. In addition air-conditioned tourist courts are close by.

Registration fee for the course is $25. Dr. J. D. Lindsay, head of the chemical engineering department, A & M College, College Station, Texas, is in charge of the course. Assisting him in setting up the program are R. A. Brannon, Humble Pipe Line Co.; A. B. Campbell, the National Association of Corrosion Engineers; Charles G. Gribble, Jr., the Metal Goods Corp.; Norman Hackerman, the University of Texas; Gustave Heinemann, Southern Alkali Corp.; Thomas F. P. Kelly, the Mavor-Kelly Co.; David Henry Levy, Magnolia Pipe Line Co.; Oliver Osborn, Dow Chemical Co.; A. L. Stegner, Tennessee Gas Transmission Co.; Starr Thayer, consulting engineer; William A. Wood, Jr., Products Research Service, Inc. Additional information may be obtained from J. D. Lindsay, Chemical Engineering Dept., A & M College, College Station, Texas.

Cathodic Protection Is UCLA Short Course Topic

Inexperienced personnel will learn practical installation and maintenance of cathodic protection systems in the field at the University of California at Los Angeles Corrosion Short Course to be held Nov. 16-18.

Subject matter will be covered in six hours each day, three hours in the mornings and three hours after lunch. Course of study will concern Basic Electro Chemical Principles (4 hours), Corrosion Circuit Theory (1 hour), Corrosion Engineering (2 hours), Instruments and Measuring Techniques (4 hours), Design and Application of Cathodic Protection (4 hours) and Economics of Cathodic Protection (2 hours). Attendance at the course will be limited to 40 persons. It will be held at 813 S. Hill St., Los Angeles, Calif.

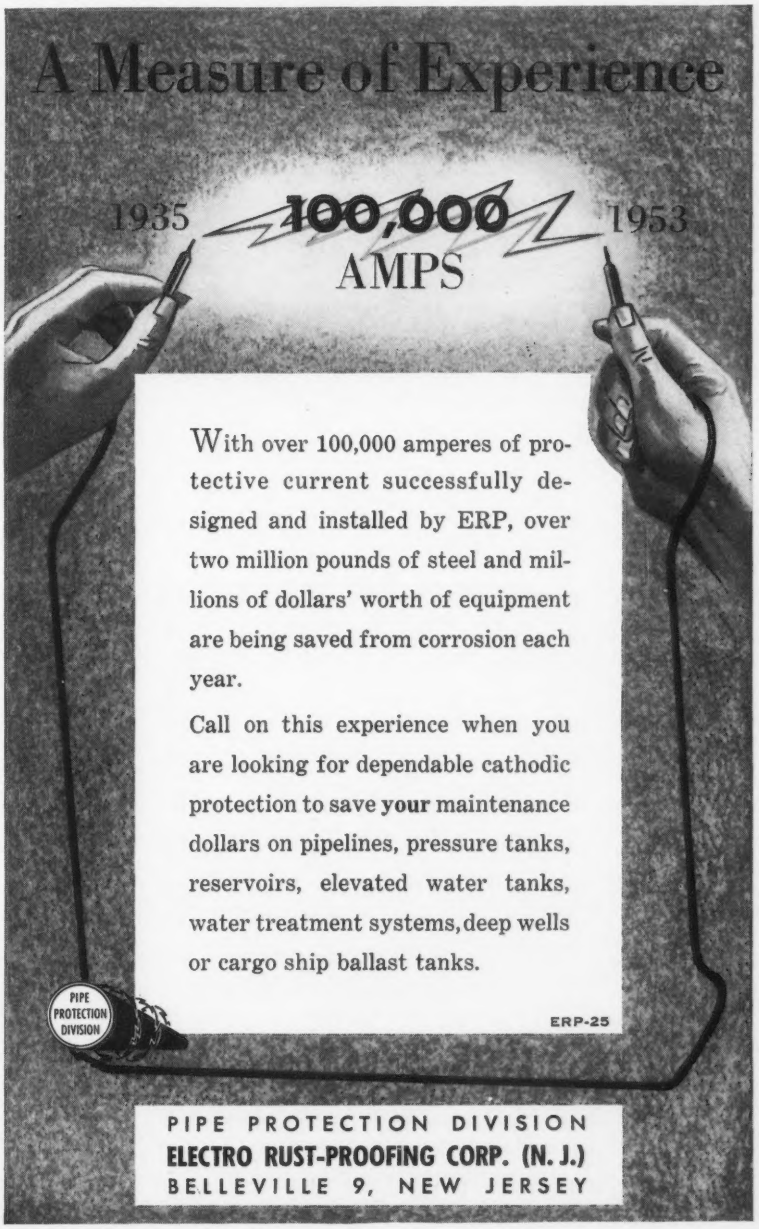
The course will be held three days immediately preceding the Western Region Conference, to be held Nov. 19 and 20.

Laboratory Work to Be Illinois Course Feature

Laboratory work under staff supervision will be a feature of the Short Course on Cathodic Protection presented at the University of Illinois at Champaign-Urbana, October 12-16. The university's engineering experiment station includes a cathodic protection laboratory which has been conducting research for the past two years. The course is jointly sponsored by the university and the National Association of Corrosion Engineers.

The complete program was published in Corrosion's July issue, page 13.

The course will be conducted by means of lectures, demonstrations, laboratory work and round table sessions. The sessions are intended to give operating and engineering personnel a highly practical course. A college degree is not required, but a knowledge of the usual mathematics used by today's practicing engineer is assumed. Cost of the course is $37.50. An additional charge of $10 will pay for 5 luncheons and the banquet. Registration information may be obtained from R. K. Newton, supervisor of engineering extension, 713½ S. Wright St., Champaign, Ill.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70 Exhibits Are Planned for Permian Basin Tour

PERMIAN BASIN SECTION members are shown here conferring on plans for the third biennial Corrosion Tour scheduled to be held September 30-Oct. 2. Left to right are John A. Knox, The Western Co., Midland, secretary-treasurer; Thomas M. Newell, Cardinal Chemical, Inc., Odessa; Lamar F. Sudduth, Stanolind Oil & Gas Co., Midland and E. O. Kemper, Permian Enterprises, Inc., Odessa, members of the Corrosion Tour Steering Committee.

Non-Technical Events For Tour Are Listed

Non-technical events of the 1953 Permian Basin Corrosion Tour will include outstanding speakers after dinner and a barbecue served by the Odessa Chuck Wagon Gang.

Lincoln Hotel, Odessa, will be tour headquarters.

Registration fee is $17.

Registration and other information can be obtained from: John A. Knox, Secretary-Treasurer, The Western Company, Box 310, Midland, Texas. Hotel room reservations should be sent directly to National Association of Corrosion Engineers, Permian Basin Section, care of Lincoln Hotel, Odessa, Texas.

40 Hear Waldrip At Odessa Meeting

Odessa Section members attending the June 15 meeting held in the Lincoln Hotel in Odessa, Texas heard Harry E. Waldrip, Gulf Oil Corp., Houston, Tex. as the technical speaker. "Have You a Production Corrosion Problem?" was the title of his talk. Mr. Waldrip is chairman of the NACE South Central Region.

Among the 40 guests present was Lyle R. Sheppard, Shell Pipe Line Corp., Houston, chairman of Technical Practices Sub-Committee No. 2A on Correlation of Data From Operating Installations, and of Technical Practices

(Continued on Page 8)

NOW FOR THE FIRST TIME GLASS LINED STEEL PIPE
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For high temperature applications
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To provide: smooth surface, low friction
abrasive resistance • sanitation
3" maximum outside dia. x 21' maximum length
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Millions of Dollars Worth of Equipment To Be on Display

More than 70 exhibits of oil field equipment will be available for inspection on location during the Sept. 30-Oct. 2 Permian Basin Corrosion Tour. The 3-day event, the third to be held under the auspices of the Permian Basin Section of the National Association of Corrosion Engineers, is expected to be the largest in point of exhibits and attendance of the events held so far. At the 1951 Corrosion Tour registrants from 38 states and three foreign countries participated.

The principal advantage offered by the Corrosion Tour over other meetings and over independent investigations of the same nature is that by arrangement through the members of Permian Basin Section millions of dollars of oil field equipment are made available for study during the three days. Actually, an interested investigator can see more equipment and evaluate corrosion mitigation efforts on more equipment during the tour than he would be able to cover in months or years of independent investigations.

Inspections In Place

The tour provides a means whereby oil field equipment may be inspected in place. Registrants are taken by bus to field locations for the inspections and after the inspections the equipment and mitigation methods are discussed.

Arrangements for the 1953 tour indicate more than 70 exhibits will be ready for inspection. Some of the equipment is the same as that which has been viewed during the two previous tours and in many the results of 6 years' service may be evaluated. Tanks and pumps will be opened up, pipes and sucker rods exposed and a complete refinery tour conducted. Fourteen types of equipment are to be viewed: including tanks, troughs, casing, well headers, pipe lines, heaters, injection equipment, slip sleeves, corrosion coupons, sucker rods, pumps, flow lines, treaters and refinery equipment generally.

Evidence of corrosion in the form of scale, the effectivenes of protective coatings, paraffin buildup, pitting and other corrosion effects will be seen. Included among the mitigation methods under inspection will be plastic and galvanized coatings, cement and alloy linings, alloy and plastic pipe, inhibitors and cathodic protection.

Many Companies Participate

The 1951 tour registrants were able to inspect equipment placed on view by the Shell Oil Company, Continental Oil Co., Humble Oil and Refining Co., Humble Pipe Line Co., Stanolind Oil and Gas Co., Atlantic Refining Co., Cosden Petroleum Corporation, Cities Service Oil Company, Sun Oil Company, Magnolia Petroleum Company, Kewanee Oil Company, The Texas Company, Texas-New Mexico Pipe Line Company, Richardson and Bass, Amon G. Carter Foundation, and Gulf Oil Corporation.

(Continued on Page 8)

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"COPON" is now giving industry a truly remarkable new kind of protection against rust and corrosion from chemical fumes, acids, caustic, alkali and salt water. And it is combining its revolutionary protective qualities with other such desirable features as remarkable elasticity, exceptional long life, phenomenal tenacity to all types of metals. May we give you more facts—or send you sample for your own testing?

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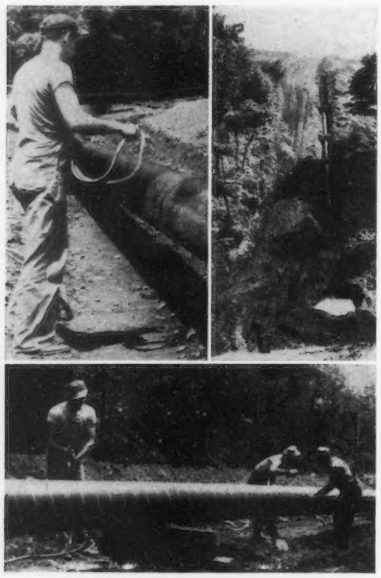

Upper Right—An Equitable Gas System 20" line through rough country. Upper Left—First coat of Roskote being sprayed on this line in the field, no primers needed. Bottom—The pipe is then wrapped with Royston Glas-Wrap and given a second coat of Roskote.

Not just the easy jobs for Roskote! It's tough enough to withstand the abrasion and corrosion of any soil, keeps its flexibility from -40° to 375°F. without brittleness or sag. Utility and pipeline companies know they can forget their corrosion worries when their pipe is "Roskoted". Roskote is applied cold, dries fast to save time and is non-toxic. It resists acids, alkalies and moisture—has an electrical resistivity of 20 megohms per square foot.

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South Central Region's October 7-9 Sessions To Feature Committee Meetings, Oil Program

Meetings of eight technical committees and a program emphasizing oil transportation, production and refining are scheduled for the October 7-9 South Central Region NACE meeting at Tulsa. It will be the second regional meeting held at Tulsa, the last there being in 1949. The Mayo Hotel will be headquarters.

The arrangements committee, headed by L. A. Hugo, Phillips Petroleum Co., Bartlesville, is preparing for 500 registrants. An entertainment program for the 100 or more wives expected to come to Tulsa is being arranged.

Besides Mr. Hugo, other members of the arrangements committee include: Registration, Fred M. Cloninger, Texas Pipe Line Corp.; projection, J. N. Hunter, Service Pipe Line Company; field trips, R. J. LaFortune, Reilly Tar & Chemical Co.; finance, E. J. Liggett, Johns-Manville Sales Co.; local arrangements, Frank McNulty, Protecto Wrap Co.; entertainment, Robert M. Nee, Middle West Coating & Supply; publicity, T. D. Williamson, Jr., T. D. Williamson, Inc.

W. H. Stewart, Sun Pipe Line Co., Beaumont, chairman and Scott P. Ewing, Carter Oil Company, Tulsa, co-chairman of the technical program committee have arranged a program to cover the latest practical developments in the battle against corrosion. A tentative program has been outlined as follows:

Wednesday, October 7

Morning and afternoon meetings of the following technical committees have been arranged:

TP-1 on Corrosion of Oil and Gas Well Equipment.

TP-6B on Protective Coatings for Resistance to Atmospheric Corrosion.

TP-6E on Protective Coatings in Petroleum Production.

TP-8A on Corrosion by Gulf Coast Cooling Waters.

TP-14A—Electrical Holiday Inspection of Coatings.

TP-18A on Internal Sour Crude Corrosion of Pipe Lines and Tanks.

Other committees besides these may meet also.

A fellowship hour will be featured in the evening.

Thursday, October 8

Morning: Pipe Line Corrosion Forum, Oil and Gas Production Symposium.

Afternoon: Pipe Line Corrosion Forum, Processing Plant Symposium.

TP-1D on Sour Oil Well Corrosion.

A banquet will be held in the evening.

Friday, October 9

Morning: Oil and Gas Transportation Symposium.

TP-1H on Corrosion of Oil String Casing.

Noon: Business luncheon.

Afternoon: General Round Table Discussion on Oil and Gas Transportation.

Achema Meeting Set

In 1955, the ACHEMA XI, Chemical Engineering and Equipment Exhibition, will be held in Frankfurt am Main, Germany, from May 14 to 22.

BOOK REVIEWS

Recommended Practices for Spot Welding Aluminum and Aluminum Alloys. 33 pages, 6 x 9 inches, paper cover. 1953. American Welding Society, 33 West 39th St., New York 18, N. Y. Per Copy $1.00

This booklet, prepared by the American Welding Society's Resistance Welding Committee includes sections on material characteristics, surface preparation, welding schedules, welding technique and defects and causes. A bibliography with 58 references on aluminum spot welding is included.

Corrosion Resistance of Copper and Copper Alloys. 28 pages, 8½ x 11 inches, paper cover. 1952. The American Brass Company, Waterbury 20, Conn. Free.

This is a revised second edition of the findings of the American Brass Company's technical staff on the corrosion of copper and copper alloys. The contents include a discussion of the theory of corrosion and types of attack, general discussion of the corrosion resistance of copper alloys and charts in which various kinds of copper and its alloys are rated against several hundred corrodents. Anaconda alloys are tabulated by number, alloy name, group name and indexed to a table of properties of these alloys.

40 Hear Waldrip—

(Continued from Page 6)

Sub-Committee No. 14A on Electrical Holiday Inspection of Coatings. C. Anderson, Crane Co., Chicago, Ill., and a NACE member was a guest.

The Corrosion Tour to be held Sept. 30 through Oct. 2 was discussed. Plans are being made and publicity organized and distributed. Steering Committee for the tour is composed of Lamar Sudduth, Stanolind Oil and Gas Co., Midland, Texas; John Watts, Humble Pipe Line Co., Midland, Texas; and E. O. Kemper, Permian Enterprises, Inc., Odessa, Texas.

70 Exhibits—

(Continued from Page 6)

Refinery Tour Scheduled

One of the features will be a tour of the modern Cosden Refinery. In 1951 the refinery tour provided valuable information on the effects of chrome alloys for cracking lines, Monel linings on mercaptan heaters, cavitation in a centrifugal water pump and water treatment.

Other significant corrosion mitigation measures used at this refinery also were viewed. This refinery uses the effluent from the Big Spring sewage disposal system as a water supply. The water is treated before use and the resulting water is satisfactory except that no brass or bronze fittings can be used because of the ammonia and other organic matter in it.

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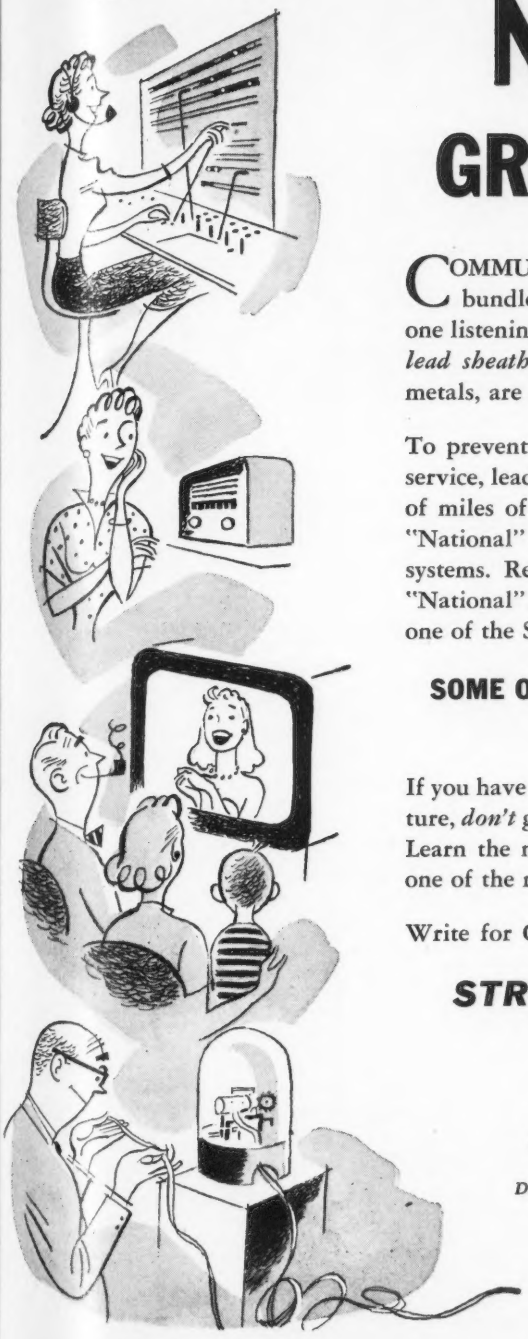

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COMMUNICATIONS, too, have their "pipelines"... huge bundles of underground wires welding the continent into one listening, looking, talking community of interest. And the *lead sheathes* that cover these vital lines, like other buried metals, are subject to damage by corrosion.

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E. G. Holmberg—Mr. Holmberg, who is with Alloy Steel Products Co., Linden, N. J. was co-chairman of the Chemical Industry Symposium at Chicago in March, 1953. He is chairman of the symposium for Kansas City.

•

Hugh P. Godard—With Aluminium Laboratories Ltd., Kingston, Ontario, Mr. Godard is chairman of the Inter Society Corrosion Committee, a member of the NACE board of directors representing corporate members, a member of the association's Abstract Committee and a contributor of technical material to Corrosion. Mr. Godard is chairman of the Corrosion Principles Symposium.

•

Thomas P. May—Long active in NACE affairs, Mr. May is on the Corrosion Engineering Section staff of The International Nickel Co., Inc., New York. Besides being a consistent contributor of technical material for publication in Corrosion, Mr. May is chairman of the NACE Editorial Review Committee and has been a member of this committee for many years. He is co-chairman at Kansas City for the Corrosion Principles Symposium.

•

F. N. Alquist—Mr. Alquist, who is with Dow Chemical Company, Midland, Mich. has contributed technical material to Corrosion on inhibitors and waters. He was formerly chairman of the NACE Editorial Review Committee and is chairman of Technical Practices Committee 13 on Annual Losses Due to Corrosion. He is a long time member of and active in association affairs. He is chairman on the Cost of Corrosion Symposium at Kansas City.

•

R. C. Buchan—Chairman of Technical Practices Committee 1 on Corrosion of Oil and Gas Well Equipment, he was co-chairman of the Chicago Oil and Gas Production Symposium. He is with

(Continued on Page 16)

2 Papers, Discussion Are Scheduled for Refinery Industry

Chairmen have been named for two symposia scheduled in the 1954 Kansas City Conference technical program. These are the last two to be named. At the same time co-chairman for three of the symposia have accepted appointments. These virtually complete the naming of officials who will have charge of the presentation of technical papers and discussion sessions.

The two new chairmen are O. W. Wade, senior corrosion engineer, Transcontinental Gas Pipe Line Corp., Houston who will handle the Cathodic Protection Symposium and Y. W. Titterington, Pipe Line Anode Corp., Tulsa, who will have charge of the Pipe Line and Underground Corrosion Round Table.

Co-chairmen named are: T. P. May, The International Nickel Co., Inc., New York, for the Corrosion Principles Symposium; E. L. Haile, Monsanto Chemical Co., Texas City, for the Non-Destructive Testing Symposium and F. M. Watkins, Sinclair Research Laboratories, Inc., Harvey, Ill., for the Refinery Industry Symposium.

Symposium Is Complete

First symposium to be completed is that for the Refinery Industry. E. H. Tandy, Standard Oil Company of California reported that arrangements have been made for presentation of two formal papers and a round table discussion. One of the scheduled papers is that by H. H. Bennett, Socony-Vacuum Oil Co., Paulsboro, N. J. on inhibitors in the refinery industry. The other paper by R. J. Hafsten, Standard Oil Co. (Indiana), Whiting, Ind. deals with corrosion of refinery equipment by sulfuric acid and sludges.

The papers are scheduled to take an hour's time and the balance of the session will be devoted to an informal discussion of refinery problems and their solution.

Other Papers Committed

M. G. Fontana and F. H. Beck of Ohio State University plan to present a paper on nitric acid, the details of which have not yet been determined. Several other papers in the Chemical Industry Symposium in which this paper will be presented are under consideration, it was reported by E. G. Holmberg, Alloy Steel Products Co., Inc., Linden, N. J., chairman of the symposium.

The scheme for the Educational Lectures has been outlined as follows by R. C. Weast, Case Institute of Technology, Cleveland: Three lectures on the topics corrosion fundamentals, cathodic protection and corrosion testing.

Two Paint Papers Accepted

N. K. Senatoroff, Southern Counties Gas Co., Los Angeles, chairman of the Protective Coatings Symposium reported two papers have been accepted: Laboratory and Plant Evaluation of Liquid

(Continued on Page 16)

Johns-Manville TRANTEX *polyvinyl* TAPE

gives lasting protection against corrosion

YOU CAN MAKE emergency repairs quickly and economically right in the field with Johns-Manville Trantex Tape. This pipeline protective material is especially suitable for repairing damage to enamel coatings or holidays in coatings.

Trantex is recommended for field coating the joints of mill wrapped pipe. It also has many advantages for coating lateral lines and short runs where heavy duty coating equipment is not available. Save on emergency coating repairs too, by keeping a supply of Trantex in your warehouse for rush requirements.

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Insulation Resistance, greater than (ASTM-D-257-49)	100,000 megohms	100,000 megohms
Temperature Limit	200 F	200 F
Adhesion oz. per inch width	30	20
Tensile Strength lbs. per inch	30	56
Elongation at Break	250%	300%

"Trantex" is a black polyvinyl tape. It is available in two thicknesses—
*V-10 is a 10 mil tape for average conditions, and
**V-20 is a 20 mil thickness for use where a more rugged coating is specified such as to repair enamel coatings.

JM PRODUCTS

Johns-Manville TRANTEX *polyvinyl* TAPE

Corrosion Sessions—

(Continued from Page 2)

ered corrosion in sweet and sour oil wells and casing corrosion in general. Carl Moore and Mr. Parr, explained the Parkerizing process and showed panels in which the advantages of a phosphate undercoat were demonstrated.

A general discussion followed the formal talks.

The group visiting Houston were part of a group of 27 scientists from Western Europe brought over to the United States to inspect corrosion mitigation practices in this country. Prior to coming to Houston they had inspected plants and talked to engineers doing corrosion work in the East and Middle West. The group was divided into segments according to special interests.

Some members of the group showed an interest in the manner in which NACE originated and how it was organized. One of the visitors intimated that the organization in Western Europe of a group similar to NACE was contemplated.

Foreign Scientists Present

The visiting foreign scientists were:

Austria: Arnulf Mathisachitz, Reischekstrasse 37, Linz/Donau.

Belgium: Roger DeSmet, 127, Avenue Montjoie, Uccle-Bruxelles; Jacques J. Trachet, Le Gros Tiene, a Ohain (Brabant).

Denmark: Erland Andersson, Fortgard Alle 18, Kastrup; Arne Andreasen, 72 Norregade, Grindsted.

France: Jean M. Barbier, 7, rue St. Dominique, Paris (7°); Emile M. Elchardus, 28, Cours Franklin Roosevelt, Lyon (Rhone); Henry G. Moreau, 7, rue Blanchard, Fontenay-aux-Roses (Seine); Pierre Muffat, rue du Commandant Arnould, Bordeaux (Gironde); Pierre L. Roblin, due de l'Industrie, Vizille (Isere); Jean Tourret, 30, rue du General de Gaulle, Enghien-les-Bains (Seine et Oise).

Germany: Immanuel F. Class, IV Gartenweg 11, Ludwigshafen/Rhein; Erich Rabald, Sandhoferstr. 116, (17a) Mannheim-Wa.

Italy: Guiseppe Basilisco, Aquilinia V-1, Trieste; Enrico Donati, Dalmine (Bergamo); Mario Jacopetti, 104, via Michele Kerbaker, Napoli.

Netherlands: Claas J. van Riemsdijk Kreenen, Laurillardlaan 16, Santpoort.

Norway: Ole Thome-Johannesen, Bakkerudvn. 13a, Nordstrandshogda, Oslo.

Sweden: Gosta M. Frang, Adelgatan 4, Oskarshamn.

Turkey: Necati Palabiyikoglu, Barut Fabrikasi, Hazirlik ve Kontrol Muduru, Elmadag, Ankara; Rasit Tolun, Etibank, Ankara.

United Kingdom: Ernest A. Blackwell, (OEEC Secretary) 4, avenue Den Doorn, Uccle, Brussels, Belgium.

NACE members participating were:

W. F. Rogers, Gulf Oil Corporation, Houston, Texas, presiding; Stan Beeler, Reynolds Metals Company, Louisville, Ky.; H. L. Bilhartz, Atlantic Refining Co., Dallas; A. B. Campbell, NACE, Houston; E. P. Doremus, Cathodic Protection Service, Houston;

L. E. Heinen, Tube-Kote, Inc.; Derk Holsteyn, Shell Oil Company; T. J. Hull, NACE; T. F. P. Kelly, Mavor Kelly Co.; J. E. Loeffler, Thornhill-Craver Co., all of Houston.

Boyd Mayes, Mayes Brothers, Inc., Houston; Paul Miller, Texas Pipe Line Company, Houston; C. W. Moore, Parker Rust Proof Company, Dallas; Marshall Parker, Cormit Engineering Company, Houston; M. A. Parr, Parkerizing, Inc., of Texas, Houston;

F. A. Prange, Phillips Petroleum Co., Bartlesville, Oklahoma; L. G. Sharpe, Humble Pipe Line Company; Lyle R. Sheppard, Shell Pipe Line Company; Starr Thayer, Consulting Engineer; H. E. Waldrip, Gulf Oil Corporation, all of Houston.

Others present were: John E. Bach, Mutual Security Agency, Washington, D. C.; W. H. G. FitzGerald, Metallurgical Research and Development Co., Washington, D. C.; C. E. Kiang, Chemical Petroleum Corp., Nationalist Chinese Republic, Formosa; Joseph Koski, Mutual Security Agency, Washington, D. C.; N. E. Philpot, Mutual Security Agency, Washington, D. C.

International Mechanical Engineering Congress Set for Turin, Italy

The Fifth International Mechanical Engineering Congress will be held from Oct. 9 to 15, 1953, at Turin, Italy. Theme for the Congress is "Production and Assembly Methods for Components in Mechanical Engineering." The main objective will be to examine and compare both from the technical point of view and from the standpoint of production costs, the various methods available to industrialists for the design and manufacture of components.

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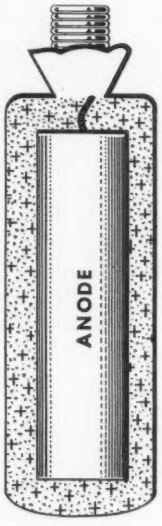

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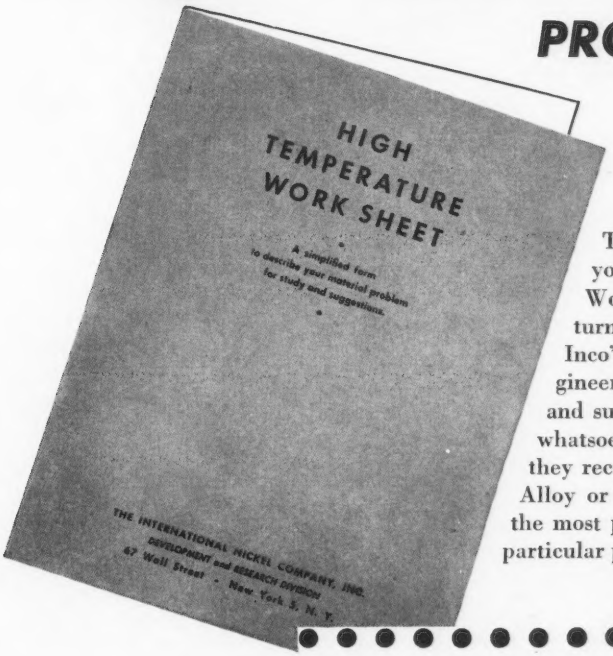
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C. 8-53

Technical Program on High Alloy Castings Held at Inco Harbor Island Station

A technical program devoted to discussions of high alloy castings in high temperature and corrosion applications was given May 12-14 at the Harbor Island Corrosion Testing Station of the International Nickel Company, Inc. Attending were members of the Alloy Casting Institute and representatives of companies manufacturing industrial furnaces and other products using high alloy castings.

First day was devoted to developments in the field of corrosion resistance, with F. L. LaQue, head of the Inco corrosion research section, discussing alloys for use in sea water. E. A. Shoefer, executive vice-president of the Alloy Casting Institute, then explained the importance of specifying cast alloys with a designation system based on the chemistry of the cast materials. He pointed out some castings users designated alloy types by AISI numbers which apply to wrought materials only. R. J. Wilcox, chief metallurgist for Michigan Steel Casting Co., pointed out that the corrosion resistance of corresponding grades of wrought and cast alloys is about the same although the higher silicon content of cast materials results in a slightly greater corrosion rate in nitric but a somewhat lower rate than wrought in sulfuric, phosphoric and certain organic acids.

Surface Finish Effects

R J. Allen of the Worthington Corporation said his company is investigating the effect of surface finish on corrosion resistance of cast and wrought alloys. Initially, he said, an attempt will be made to isolate significant factors, such as porosity and microstructure, carbon content, and the effect of different types of foundry sand.

Three primary methods of avoiding intergranular corrosion were discussed by John Juppenlatz, chief metallurgist for Lebanon Steel Foundry. These are, solution heat treatment, which assures complete solution of carbon; use of stabilizing elements such as columbium, tantalum and titanium, and reduction of carbon content to less than 0.04 percent.

Other Corrosion Effects

W. A. Luce of The Duriron Company said service data indicate no deleterious effect from ferrite, at least in media for which alloys are recommended normally. Certain reducing acids will attack ferrite selectively.

Corrosion by liquids at elevated pressures and temperatures was discussed by M. G. Fontana of Ohio State University and R. Matters, Allis-Chalmers Mfg. Co. They reported few data are available on this subject but current studies indicate corrosion increases rapidly at temperatures above boiling and at high pressures.

C. E. Peck, Westinghouse Electric Corp.; George McCormick, Industrial Heating Equipment Co. and R. J. Perrine, Electric Furnace Company, members of the Technical Advisory Committee of the Industrial Furnace Manufacturers Association, participated in a symposium titled "Corrosion Problems in Furnace Design," with R. H. English, of National Alloy Division of Blaw-Knox Company. They indicated that below approximately 1850 degrees F the higher chromium-lower nickel alloys are acceptable generally while above this temperature the higher nickel-chromium alloys are desirable.

At high temperatures ordinary air appears more corrosive than oxidizing flue gases, except where these have a high sulfur content, Mr. English said. Reducing flue gases containing sulfur are particularly harmful to nickel-chromium alloys and to high nickel alloys in general, he reported. Cyclic heating increases the severity of corrosion. Green rot, which follows when hydrogen or reducing atmospheres are present is caused by selective oxidation of the chromium. In very high nickel-chromium alloys this will occur at temperatures as low as 1500 degrees F, but will seldom occur in the nickel-chromium-iron alloys under 1900 degrees F and then only when chromium is on the low side.

High Temperature Corrosion

Lower nickel alloys are most satisfactory for flue gases containing over 100 grains of sulfur, J. H. Jackson of Battelle Memorial Institute said. In flue gases with low sulfur nickel reduces corrosion and an addition of about 1¼ percent silicon is beneficial also.

E. N. Skinner of Inco research and development division said resistance to scaling in systems with cyclic heating and thermal shock was best in high nickel alloys containing suitable chromium content and low in harmful impurities, while resistance to corrosion in nitriding atmospheres was best in high nickel cast alloys such as HX grade (67 Ni, 17 Cr).

Ceramic Coatings

Don Helman, metallurgist for Ohio Steel Foundry Company, said claims listed about ceramic coatings in the aircraft industry included lengthened service life of present alloys, operation at above-normal temperatures and reduction of strategic elements. The ability of ceramic coating to protect underlying metals successfully depends on their ability to remain unbroken at high temperatures.

Norman A. Matthews of American Brake Shoe Company's research laboratories said a cast alloy suitable for use at 2000-2200 degrees F temperatures is needed.

JOSEPH B. DONNELLY

Joseph B. Donnelly, a member of the National Association of Corrosion Engineers since 1944 died recently. Mr. Donnelly was working with the Department of Public Property, Philadelphia, Pa., at the time of his death. Part of his corrosion experience was preventive work on corrosion due to electrolysis from electric railways.

•

An award is made annually by NACE to the author or authors whose paper published in CORROSION is judged best of those published by authors under 35.

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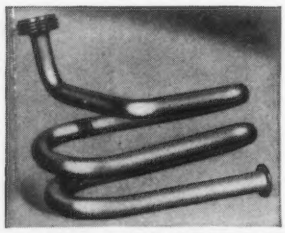

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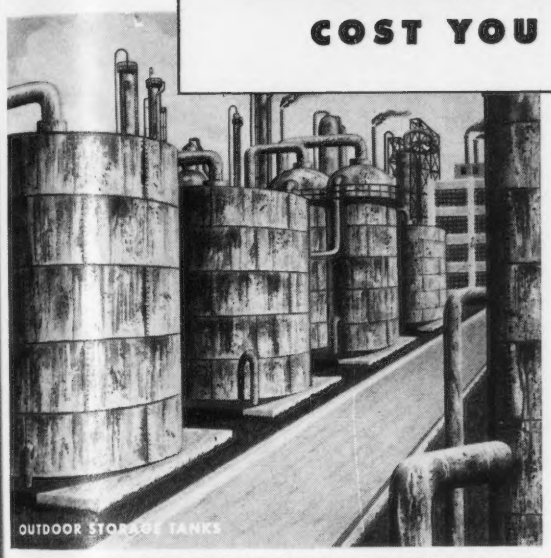

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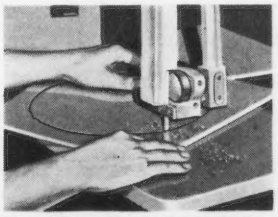

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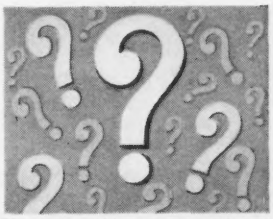

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Who's Who—

(Continued from Page 10)

Humble Oil and Refining Co., Houston and has had many years of experience coping with corrosion problems in his industry. He is chairman of the Oil and Gas Production Symposium at Kansas City.

•

E. C. Greco—Co-chairman of the Kansas City Oil and Gas Production Symposium, Mr. Greco is supervisor of the Water and Corrosion Chemistry Section, Research Dept., United Gas Co., Shreveport, La. A 1934 graduate of Northwestern Louisiana College, Mr. Greco has spent 15 years in corrosion work. He is vice-chairman of TP-1, and chairman of the Natural Gasoline Association of American Corrosion Committee. During the war he was Chief Explosives Chemist for U. S. Army Ordnance and Special Chemist, Development, E. I. DuPont Explosives Division. A councillor for the American Chemical Society, he is chairman of the finance committee of the Louisiana Academy of Sciences and a member of the American Association for the Advancement of Sciences.

•

R. M. Lawall—Chairman of the Kansas City Power and Communication Symposium, he was co-chairman of the session of the same name at Chicago. Mr. Lawall, who is with the American Telephone & Telegraph Co., Cleveland, is chairman of NACE Technical Practices Committee 16C on Cathodic Protection of Cable Sheaths. Mr. Lawall has long been active in corrosion mitigation work.

N. K. Senatoroff—Mr. Senatoroff, who is with Southern Counties Gas Co., Los Angeles, was co-chairman of the Protective Coatings Symposium at Chicago last March. As chairman of the symposium of the same name at Kansas City he already has reported substantial progress in securing papers. Mr. Senatoroff, who holds NACE membership No. 202, has been a member of the association since 1944. A graduate of California Institute of Technology in Chemical engineering he has been concerned with underground and other types of corrosion since 1929.

•

Walter B. Meyer—Mr. Meyer is co-chairman of the Protective Coatings Symposium. He is president of St. Louis Metallizing Co., St. Louis, Mo. and is a graduate of Illinois College, Jacksonville, Ill. His experience with coating problems began in 1936 when he was sales and service engineer for Metallizing Engineering Co., Long Island City, N. Y. Since 1939 he has been with Nooter Corp. and since 1952 with St. Louis Metallizing Co. He is past chairman of the National Committee on Metallizing of the American Welding Society.

•

Edward H. Tandy—Mr. Tandy, head equipment inspector at Standard Oil Company of California's El Segundo refinery, is chairman of the Refinery Industry Symposium. Since 1938 he has been concerned with materials, corrosion and equipment inspection at the Richmond and El Segundo refineries.

•

R. C. Weast—Mr. Weast, who presented one of the very popular educational lectures on corrosion fundamentals at Chicago, is chairman of the Educational Lectures feature for the Kansas City meeting. He is with Case Institute of Technology, Cleveland.

Five More Kansas City—

(Continued from Page 10)

Neoprene Coatings by R. B. Seymour, Atlas Mineral Products Co., Mertztown, Pa. and a second paper by J. Robert Spraul, manager of the research and testing laboratory, General American Transportation Co., East Chicago, Ind., on Coating Testing for Tank Car Linings. Other potential papers are under consideration.

International Engineers Conference Set for Rome

The First International Engineers' Congress, sponsored by the Fédération Internationales des Associations Nationales d' Ingénieurs (FINI), will be held in Rome, Italy, October 8-11, 1953. General subject of the sessions will be, "Preparation of the Engineer for His Place in Society." The engineer's place in the field of the technical professions, in the economic field, in public life, in the social structure of the nation, in the whole body of professions, his place in "the arising Europe," will be discussed in reports and meetings. More information on the congress may be obtained by writing the Italian Executive Board, First International Engineers' Congress, c/o ANIAI—Rome 90, Via Terme Diocleziano. Several tours have been arranged for those attending the congress.

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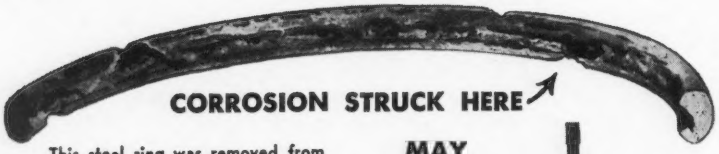

CORROSION STRUCK HERE

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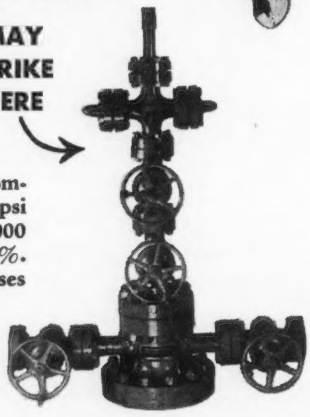

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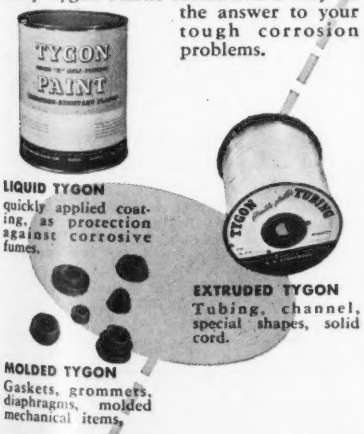

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British Aluminum Association Offers Exchange Of Information on Surface Preparation

Negotiations are now in progress for an exchange of information between Technical Practices Sub-Committee No. 6G on Surface Preparation for Organic Coatings and the Aluminium Development Association, an English technical society with headquarters in London, England.

Cooperation of the Aluminium Development Association was offered in response to a letter from NACE Sub-Committee Chairman L. R. Whiting, proposing an exchange of information. Writing for the English society, A. W. Brace, assistant metallurgist stated, "We are most interested to note this proposal, and feel it would be to our mutual advantage if further details could be exchanged between us." He explained that the Aluminium Development Association is now assessing various methods of surface preparation of aluminum, particularly as it is used in larger structures such as crane jibs, bridges, mining equipment, chemical and petroleum industries, plants and shipbuilding, because these larger structures present different problems than surface preparation of smaller components made of aluminum.

Mr. Brace also enclosed a booklet, "Painting Practice for Aluminium," Aluminium Development Information Bulletin No. 20. The 19-page booklet, is devoted to instructions on cleaning and degreasing, pretreatment, choice of paint system, repainting and specifications relevant to the painting of aluminum.

Three Subgroups Are Formed in Transportation Industries Committee

Formation of three new subcommittees of Technical Practices Committee No. 15 on Corrosion Control in the Transportation Industries has been announced by Kenneth K. Kessler, chairman of the parent committee. The new subcommittees are: Technical Practices Subcommittee No. 15A on Corrosion Control of Railroad Tank Cars, J. R. Spraul, chairman, General American Transportation Co., East Chicago, Ind.; Technical Practices Subcommittee No. 15B on Railroad Suppliers of Corrosion Resistant Materials, J. S. Swann, chairman, Standard Railway Equipment Co., Hammond, Ind.; and Technical Practices Subcommittee No. 15C on Corrosion Control in Railroad Hopper Cars, S. K. Coburn, chairman, Association of American Railroads, Technology Center, Chicago 16, Ill.

Pollution Cleanup Brings Mussels Headache to Los Angeles Steam Plant

When in industry wide anti-pollution campaign removed high sulfide content of harbor water used as a coolant by the Harbor Steam plant of the Los Angeles Water and Power Dept., plant officials found the problem of corrosion of aluminum brass condensor tubes which had threatened to close the plant was solved.

But cleaner water brought back marine animal life, including vast quantities of mussels which clogged conduits, pumps and suction strainers, threatening again to close down the plant.

Cooling water is brought to the plant through duplicate conduits, either of which will provide sufficient water under normal conditions. As a solution to the mussel problem, plant engineers sealed off one of the conduits during the spawning period. After the mussels had used up all the oxygen in the water, they died. After the first attempt more than 45 tons of dead marine life were flushed out of the conduit and the plant was back in normal operation.

The problem and its solution was discussed in a paper before The American Society of Mechanical Engineers in its July meeting.

L. R. Whiting Now Heads Surface Preparation Technical Practices Group

L. R. Whiting, formerly vice-chairman of Technical Practices Sub-Committee No. 6G on Surface Preparation for Organic Coatings, is now chairman of the committee. A second interim report, Surface Preparation of Steels for Organic and Other Protective Coatings, recently published by NACE.

TP-4 Report Made

A preliminary report by Technical Practices Committee No. 4, Minimum Current Requirements for Cathodic Protection, has been mailed to members of the committee by L. P. Sudrabin, Electro Rust-Proofing Corp., chairman. Members of the committee were asked to comment on the report.

POSITIONS WANTED and AVAILABLE

- Active and Junior NACE members may run without charge two consecutive advertisements annually under this heading, not over 35 words set in 8 point text type.
- Firms seeking employees, regardless of NACE membership, may run an advertisement of the same specifications indefinitely.
- Advertisements to other specifications will be charged for at standard rates.

Positions Available

Corrosion Engineers. Positions available for graduate electrical engineers or equal. Previous field and design experience in corrosion mitigation systems required. Extensive travel involved. Salary open. The Hinchman Corp., Engineers, Francis Palms Bldg., Detroit 1, Mich.

•

Sales Representatives for DEL Protective Coatings. Protected territories available to qualified individuals or companies. No objection to carrying non-competitive lines. Write David E. Long Corp., 220 East 42nd St., New York 17, N. Y.

•

Corrosion Engineer—Chemical or metallurgical background. Sell metallizing and hardfacing equipment in New England area for concern also equipped to do work. Right man will complete nucleus for fast growing plant. New England Hard Facing Co., 678 Brookline Ave., Brookline 46, Mass.

AGENTS WANTED

To Represent Manufacturer

Of specialized wax base anti-corrosion coatings. Should know corrosion problems of steel mills, oil refineries, sewage disposal plants, chemical plants and be familiar with the application of polyethylene and Thiokol.

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Positions Wanted

Chemical Engineer (BS), member NACE, desires New England location. Age 36. 8 years' experience process engineering, corrosion, instrumentation. Currently employed Mid-west. CORROSION, Box 53-13.

Write for Rates, 1061 M & M Bldg. Houston 2, Texas

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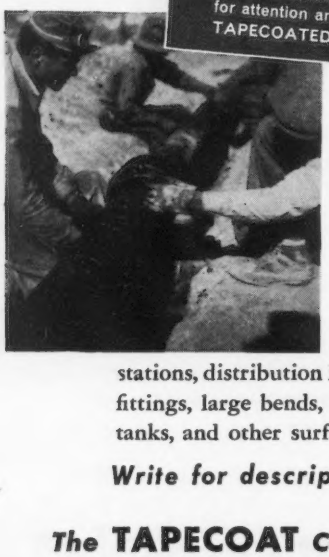
PROOF (Above ground)—A gas line at a bridge crossing was TAPECOAT-protected in 1944. There has been no need for attention and *no interruption of service* since the pipe was TAPECOATED.



Actual experiences like these show what TAPECOAT coal tar protection can do for you.

Use TAPECOAT to combat corrosion above or below ground on gathering lines, transmission lines, meter stations, compressor stations, distribution lines, pipe joints, bolt-type couplings, fittings, large bends, large diameter pipe, insulated lines, tanks, and other surfaces subject to corrosion.

Write for descriptive brochure and prices

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Originators of Coal Tar Tape Protection

1521 Lyons Street, Evanston, Illinois

$134,500 Contract for Cathodic Protection Is Given Houston Firm

A $134,500 contract for cathodic protection of 250 miles of gas distribution mains, laterals and service lines in the City of Houston has been awarded to Cathodic Protection Service of Houston, Texas, Tulsa, Okla., and New Orleans, Louisiana.

The distribution system is one of three gas utility systems in the city and one of the oldest. Except for a few thousand feet of cast iron pipe, the bulk of the system consists of steel piping. Cathodic Protection Service engineers say that most of the mains and laterals are either bare or very poorly coated. However, a large percentage of the service lines are relatively well coated.

It is estimated that cathodic protection will pay for itself in less than two years. In the late 1930's, $140,000 was spent for repairs and in 10 years $40,000 more was spent. At present an estimated $40,000 in gas escapes through leaks yearly.

The City of Houston is now replacing badly corroded pipe in the system and the gas system is being electrically isolated from water lines by the installation of insulating units at gas meters. Many service lines are tied into mains with open circuit couplings. Engineers have devised a way of "shorting" these open circuits without costly excavation.

Electrochemical Means Of Plating Aluminum On Steel Is Sought

In an effort to find a substitute for scarce tin, Virginia Polytechnic Institute is conducting a graduate research project directed toward development of an electro-chemical method of giving steel a protective coating of aluminum. If the project is successful, need for stockpiling of expensive and hard to get tin would be greatly reduced.

Tinning Oils Discovery

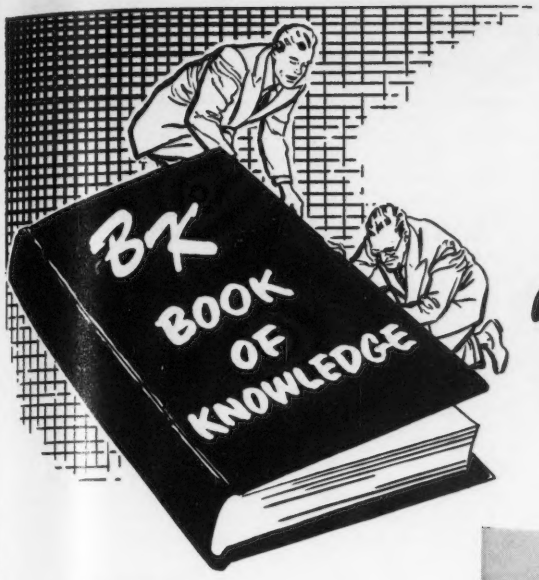
Tinning oils for hot-dip tin-plating of steel can be made by slight modification of lard, tallow, white grease and other animal fats. The discovery was made at the Armour Research Foundation of Illinois Institute of Technology Center in Chicago, Ill.

Hot Dip Galvanizers

The 1953 Semi-Annual Meeting of the American Hot Dip Galvanizers Association, Inc., will be held at the Statler Hotel in Cleveland, Ohio, Monday and Tuesday, Sept. 14, 15. As part of the program, a color corrosion film will be shown.

•

Reprints of material published in CORROSION are usually made only on order. Tentative prices may be obtained from Corrosion, 1061 M & M Bldg., Houston 2, Texas.



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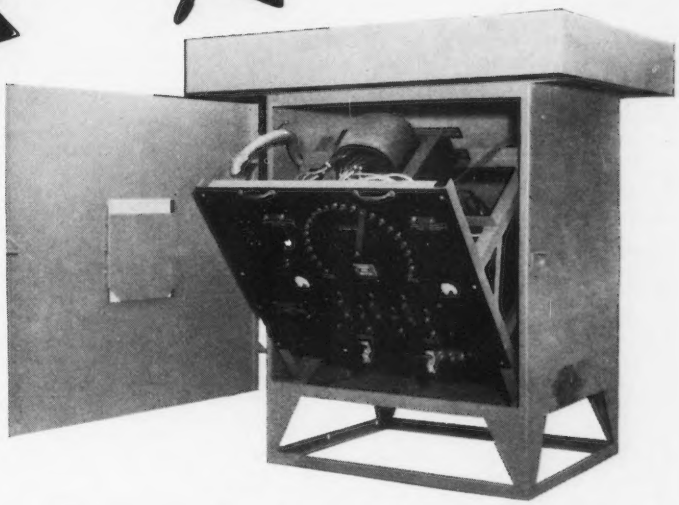

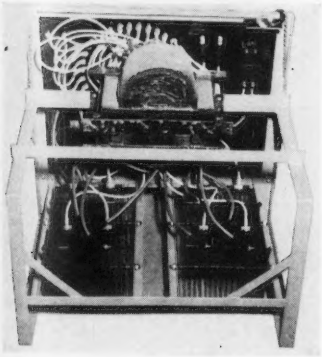

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NEW PRODUCTS —Materials—Service—Literature

Norelco portable x-ray units small enough to be put into a car trunk are being manufactured by X-Ray Dept., Non-Destructive Testing Div., North American Phillips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y. The new units are suggested for rapid field inspection of welds, pipe lines, power plants and ship and aircraft equipment. The complete unit weighs only 143 lb. Current drain is 20 amperes.

●

Edscorp Pocket Comparator for fast accurate measurement and inspection of small parts and small dimensions is being marketed by the **Edmund Scientific Corp.**, Barrington, N. J.

●

The American Smelting and Refining Co., Perth Amboy plant, Barber, N. J., has developed a continuous-cast bronze process which produces exceptional uniformity and freedom from flaws. The patented process is said to be the only continuous-casting method in commercial use producing copper-base alloy stock ready for machining or other fabrication.

●

Lonco Insulating Rosin Flux, a new activated rosin flux that insulates as it bonds and which the manufacturer says is completely non-corrosive is being marketed by the **London Chemical Co., Inc.**, 325 W. 32nd St., Chicago 16, Ill. Elimination of breakdown due to corrosion and fast fluxing action are claimed for the product.

●

Bart-Messing Corp., Belleville, N. J., announces completion of a single cubicle selenium rectifier with an output capacity of 30,000 amperes of dc power at 12 volts. The rectifier will be used to furnish low voltage dc power for electroplating nickel-lined steel pipe for Atomic Energy Commission projects.

●

Rem-Cru Titanium, Inc., 405 Lexington Ave., New York 16, N. Y. says its production of titanium has advanced to where the metal is available for many production applications.

●

Portovent, a flexible ventilating hose, is being introduced by the American Ventilating Hose Co., 100 Park Ave., New York 17, N. Y. The hose is intended to provide for ventilation and fume exhaust. It is made from cotton or nylon fabrics impregnated with Neoprene compound and spiral wire reinforced. It can be cut to size with no weakening or raveling since it is bonded and not stitched. It has unusual lengthwise compressibility and has excellent air flow characteristics and maintains a large cross section even on sharp bends.

●

Bakelite and Vinylite Resin Coatings for the Petroleum Industry, is the title of a new 8-page illustrated folder published by **Bakelite Co.**, a Division of Union Carbide and Carbon Corp., 260 Madison Ave., New York 16, N. Y. Case histories, test results and photographs of actual industrial applications of the finishes are presented in the brochure. Use of the coatings increases protection of equipment, extending its service life and reducing maintenance costs, the brochure says. The finishes are available in a variety of colors. The firm also has published **Bakelite and Vinylite Resin Coatings for the Chemical Industry** which presents 16 case histories of actual industrial coating applications.

●

Garman Company, Inc., St. Louis, Mo., has developed three products to be used in treating water cooling equipment in air conditioning systems. **Vapco Preventive**, according to the firm, "complexes" or inactivates the solids usually found in water and holds them in solution to be drained off naturally once each month instead of being deposited on metal surfaces of pipes and pumps. **Vapco Slime-X** is an organic chlorinated phenol which has been activated by incorporating a penetrant and an interface contacting agent. **Vapco Cleaner** is an acid type salt designed to remove scale and other incrustants which may have accumulated because of improper water treatment. All three products can be used without shutting down equipment.

●

Defensite Tuf-Quik Floor Enamel provides high resistance to attack by chemicals, according to **Wilbur & Williams Co.**, 130 Lincoln St., Boston 35, Mass. The paint is intended for use on wood or concrete floors.

●

Dow Corning Corp., Midland, Mich., is marketing two silicone water repellent products. **Dow Corning XS-1**, a solution of sodium salts of certain silicones will keep water from wetting paper, glass and ceramic insulator bodies, asbestos cloth, masonry walls, clay or adobe buildings and even dirt roads and irrigation ditches. Another product of the firm, **Dow Corning 1109**, a silicone water repellent treatment for leather, gives a high water repellency without appreciably altering the appearance, feel or "breathing" characteristics of the leather. The leather remains water repellent even after prolonged aging or wear.

●

F. J. Stokes Machine Co., 5500 Tabor Rd., Philadelphia 20, Pa., has published a 36-page illustrated catalogue showing uses of **Stokes Microvac Pumps for High Vacuum.** The book also contains tables and formulas, constants and conversions frequently used in vacuum processing.

●

American Locomotive Co., 30 Church St., New York 8, N. Y., describes a mass spectrometer used in testing pipe welds and welds on special types of heat exchangers and pressure vessels. The machine has wide uses in the petroleum refining, chemical, lead mining, fabricating and process industries and in many other fields.

●

Amercoat Corp., 6530 Supply Row, Houston, Texas, now has its branch offices in Houston. Larger quarters were necessary because of expanding business and markets in the Houston area, plant officials said.

●

Dowell Inc., Tulsa 1, Okla., is marketing **Corban** a corrosion inhibitor for combating corrosive well fluids. Corban is a polar type inhibitor. It is adsorbed onto metal surfaces forming a film that isolates the metal from direct contact with corrosive well fluids. It is available in solid stick form and in several different liquid compositions to meet specific well conditions. It is easy to apply, the firm claims.

●

The Insul-Mastic Corp. of America, 1141 Oliver Bldg., Pittsburgh 22, Pa., has two additional contractors licensed to market its products. The companies are: The Starr Davis Co., Inc., Greensboro, N. C.; and The Plant Asbestos Co., Emeryville, Cal. Insul-Mastic produces heavy mastic coatings for vapor-sealing insulation, waterproofing masonry and for corrosion prevention.

●

Isotope Products Ltd., Box 127, Oakville, Ont., has applied their **Gammagage** to the detection of corrosion. The machine was used to inspect parts of a refinery unit while it was in operation at a temperature of 1150° F. Corrosion was found to be within safe limits. Corrosion was also detected in a digester used in making furfural. However the main use of the Gammagage is in inspecting welds. As much as 2000 feet of welding can be inspected with a single radiograph exposure. Testing for corrosion in the internal walls of compressed gas cylinders is so accurate that even cracks and scale in the wall are

(Continued on Page 24)

REPRINT

Publication 53-I

Surface Preparation Of Steels For Organic and Other Protective Coatings

- **Second Interim Report of NACE Technical Practices Sub-Committee 6-G on Surface Preparation for Organic Coatings.**

This report itemizes the various procedures used to prepare steels for the application of protective coatings. Recommendations as to procedures, standards, safety measures are given. This second report by NACE TP-6G is the culmination of many months of work by committee members. The report has been carefully prepared and checked by committee members with long experience in the coatings application field.

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23 YEARS is a long time on the job preventing corrosion damage to underground pipe. SOMASTIC Pipe Coating has furnished complete protection at severely corrosive locations since its first year—1930.

In fact, our knowledge of its useful life is limited only by the total time it has been in existence.

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2 ECONOMICAL METHODS OF APPLICATION:

... by Central Plant

... by portable Railhead Plant

SOMASTIC PIPE COATING

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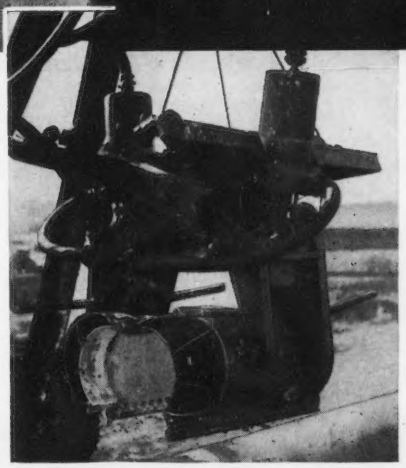
The sure protection of impervious asphalt-mastic—won't distort under soil stresses; resists shock; prevents electrolysis. Ductile; inert; firmly bonded to pipe.

RAILHEAD PLANT. Choice between railhead and central plant depends on the economics of a specific job.

HYDRAULIC FORM. Field joints make SOMASTIC protection continuous along the entire coated line.



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TNEMEC COMPANY, INC.

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NEW PRODUCTS

(Continued from Page 22)

detected. Isotope Products Ltd., is also Canadian agent for the Sempun crack detector, a magnetic flaw detector used for surface inspection. The detector was developed in England.

●

Bassons Industries Corp., 1432 W. Farms Rd., New York 60, N. Y., has published a 12-page brochure on plastic products. The brochure illustrates the uses of plastic and emphasizes its corrosion resistance and high strength to weight ratio.

●

Glasfab, inorganic glass waterproofing membrane fabric made by the **Twinsburg-Miller Corp.,** Box 207, Twinsburg, Ohio, is the subject of an illustrated, 16-page brochure entitled "Let's look at membranes." The brochure compares typical test data on the product with material specifications and also pictures Glasfab in use in the petroleum, chemical, utility and other industries.

●

Roybond A-36, a new polar, synthetic rubber-resin adhesive compound for use as a primer in the application of plastic tapes has been introduced by **Royston Laboratories, Inc.,** Blawnox, Pa. The firm says the plasticized special compound improves with time as the plasticizer blends at the interface. The product is an effective coal-tar, hot-enamel primer absorbing stress due to contraction of hot enamel.

●

The Rockwell Manufacturing Co., 400 N. Lexington Ave., Pittsburgh 8, Pa., has issued a 12-page bulletin, Bulletin V-220, describing lubricants, lubricant fittings and lubrication methods for Rockwell-built Nordstrom valves. Three major types of lubricant—**Rockwell Hypermatic, Nordcoseal** and **Lubricant DC-234**—are described, and their functions listed in detail. A "selection chart" shows which lubricants are recommended for use with a variety of fluids.

●

Apollo Metal Works, 66th Place and South Oak Park Ave., Chicago 38, Ill., produces a non-fading and corrosion resistant organic finish to be applied to aluminum, brass, steel and zinc coils in widths from one-eighth to thirty inches, 0.010 to 0.036 gauge, in continuous lengths. The finish stands up well under forming, drawing, bending or fabricating of the metal.

●

The Gerber Scientific Instrument Co., 89 Spruce St., Hartford 1, Conn., is marketing the **Gerber GraphAnalogue** which multiplies graphs or curves directly. It divides a distance into any number of equal spaces, or into logarithmically proportional lengths, or into any arbitrary nonlinear proportion.

●

The Ferro Corp., is now manufacturing and selling a new frit for the coating of aluminum. The frit, especially developed by the Dupont Company, will provide aluminum with corrosion resistance and resistance to abrasion, thermal shock, impact and flexing. The porcelain enameled aluminum is easily fabricated, it is said.

●

Owens-Corning Fiberglas Corp., Toledo 1, Ohio, has published a descriptive piece on the use of **Fiberglas.** The product can be made stronger than steel, or as light and flexible as silk, is incombustible, non-corrosive, moisture resistant, sanitary, durable and dimensionally stable, the company states. Insulation and sound deadening are two principal uses, along with use as electrical insulation.

●

The American Mollerizing Corp., Beverly Hills, Calif., states it is the first American licensee for **Mollerizing,** a process widely used in Sweden for the coating of steel with aluminum to prevent rust or corrosion. The process is said to have wide application in the industrial field where rust protection is required. It is practical for marine products, pole line hardware, milk cans, springs, steel windows, tools, automotive products, structural steel, transmission towers and other uses.

●

Flaw Location is the title of a 12-page booklet published by **Turco Products, Inc.,** Terminal Annex 2649, Los Angeles 54, Cal. The process involves using a red penetrating dye which is applied to the surface to be tested after it has been cleaned. The dye on the surface is then removed. The dye will penetrate into cracks, below the surface however and stays there until a white developer is applied. Then the dye comes to the surface, plainly visible.

●

National Instrument Co., 5005 Queensbury Ave., Baltimore 15, Md., is marketing a new measuring microscope, **Optometer Model GR.,** available in two magnifications, 20 power and 40 power. The 20 power has a field of view of .580-inch and a measuring scale reading directly to 0.002-inch. The 40-power has a field of view of 0.290 and a measuring scale reading directly to 0.001. Examining plated parts for irregular deposits, pitting, cracks and blisters is one of the many uses suggested.

●

Lucoflex has developed welding rods for non-plasticized hard vinyl plastics, which it estimates will save up to 80 percent in welding time and up to 50 percent in materials cost. The firm also makes solid bars up to 2.50 inches in diameter with uniform density which permits machining of component parts for corrosion assemblies. More information may be had by writing Harold Schor, 114 E. 40th St., New York 16, New York.

●

L. O. Koven & Brothers, Inc., Engineering Sales Div., 154 Ogden Ave., Jersey City 7, N. J., have published a three color 8-page illustrated brochure showing examples of the firm's work. Special fabrication of stainless steel and other metals for the chemical industry, food processing industry, and medical field is stressed in the brochure, although many examples of tank construction, piping and other regular construction jobs are also illustrated. The firm also provides portable x-ray examination, hot dipped galvanizing, stress relieving and normalizing and special welding services.

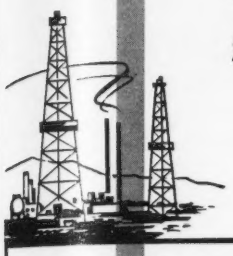
●

Dearborn Chemical Co., Chicago, Ill., announces removal of its Eastern division offices to a newly constructed building at 1601 Linden Ave., East Linden, N. J. The office formerly was in New York City. The firm makes water treatment formulas, cleaning compounds and No-Ox-Id rust preventives.

(Continued on Page 26)

STOP CORROSION
PROLONG EQUIPMENT LIFE
LOWER MAINTENANCE COSTS
SIMPLIFY LEASE OPERATIONS

with



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3 Kontol protects against all types of corrosion. The usual corrosion attacks are stopped, as are hydrogen embrittlement and hydrogen blistering.

4 Kontol also lubricates rods and tubing and reduces excessive wear due to friction and abrasion.

5 Kontol is simple to use. It is easily applied by pumping, dumping, lubricating or solid stick form.

6 Kontol is safe — no extraordinary handling precautions are necessary. No goggles, masks, aprons, rubber-gloves are required. It is non-poisonous, non-explosive and non-inflammable (under normal conditions).

7 Kontol does not render emulsified production more difficult to demulsify. It does not deposit formation plugging precipitates.

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CORROSION INHIBITING
SCALE PREVENTING
PARAFFIN REMOVING
WATER DE-OILING

KFB 53-4

NEW PRODUCTS

(Continued from Page 24)

Penetrol, a liquid designed to be applied to rusted surfaces after loose rust has been removed, is said by manufacturers to have the faculty of penetrating the residual rust to the bottoms of pits. The resulting tacky surface makes an excellent base for paint and provides an unusually good bond, manufacturers say. The liquid also may be added to paints to adjust them for application ease, but it cannot be used as a contact coat for lacquer, plastics, rubber, water paints or coal tar materials. It also is recommended for cleaning and protecting chromium automobile bumpers. Additional information may be obtained from The Flood Company, Hudson, Ohio.

●

Spot-Seal Wrap, a paper coated on one side with a pressure sensitive adhesive is available from Sherman Paper Products Corp., Newton Upper Falls, Mass. The adhesive adheres to itself but not to the uncoated side of the paper and the material is recommended for self-closing packaging purposes.

●

Walterisation, a phosphatizing process developed by The Walterisation Co., Ltd,. Purley Way, Croydon, England, produces a coating which is a pure ferrous phosphate, manufacturers say. It may be applied to ferrous surfaces, or to galvanized or other zinc-coated surfaces. Principal advantage of the process is the penetration of the coating into the base metal and the surface it provides to key paint to the metal.

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Let Pipeline Anode Corp. handle your complete corrosion protection installation
• Highest quality AN-SPEC Magnesium Anodes.
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●

Correspondence Courses providing guided study for persons who have had corrosion control responsibilities added to their duties are offered by Marshall E. Parker, Corrosion Consultant, 717A, M & M Building, Houston. The courses are aimed principally at providing training in corrosion engineering of buried and submerged structures and cathodic protection and include guidance in selection of instruments, use of instruments, conducting surveys and solving design problems. Mr. Parker has descriptive literature available on request.

●

Nitrox, a combination cleaner-corrosion inhibitor for cleaning iron and steel cargo tanks in tankers and for other containers handling light hydrocarbons, inedible oils, solvents and inorganics has been developed by Solvay Process Division of Allied Chemical & Dye Corp., 61 Broadway, New York 6, N. Y. The material is said to combine the cleaning action of caustic soda and the inhibiting action of sodium nitrite. Nitrox is produced in flake form. Literature is available.

●

Courses in plastic welding will be organized in the next six weeks by American Agile Corp., P.O. Box 168, Bedford, Ohio. The courses will cover design, theory, welding exercises, reinforcement and structural design in the handling of polyethylene, and unplasticized polyvinyl chloride and flame spraying. Complete details and information are available from the company.

●

Nylon bearings and stainless steel axles are used in the Nylo-Roll conveyor built by Metzgar Co., 496 Douglas St., N. W., Grand Rapids 4, Mich. Designed for use in dairies, creameries, canneries, meat packing plants and food processing, chemical and drug manufacturing plants, it resists corrosive conditions which destroy ordinary ball bearings.

PERSONALS

G. B. Webb has been appointed senior process engineer for Walter Kidde Nuclear Laboratories. Mr. Webb, a chemical engineer with a number of patents and publications to his credit, worked on basic design and engineering problems in connection with the gaseous diffusion plant in Oak Ridge, Tenn. and also in isotope separation work on the design of a deuterium separation plant.

●

Paul W. Bachman has been elected a vice president of the Davison Chemical Corp., Baltimore, Md. He will also continue in his position of director of research and development. Mr. Bachman is a member of The National Association of Corrosion Engineers.

●

R. Leslie Beattie, vice president and general manager of Canadian Operations of The International Nickel Company of Canada, Limited, died suddenly recently at the age of 62. Mr. Beattie was manager of the company's mines, mill, smelters, refineries and auxiliary operations in Canada. Mr. Beattie in 1911, joined the Canadian Copper Company, a predecessor of International Nickel. He is suceeded by **J. Roy Gordon,** formerly assistant vice-president. Mr.

(Continued on Page 28)

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PERSONALS

(Continued from Page 26)

Gordon joined the company in 1946 as director of the research department.

•

Kenneth L. Bullock has been appointed assistant sales manager of the process equipment division of the U. S. Stoneware Co., Akron, Ohio, according to an announcement by Howard Farkas, vice-president and general sales manager of the firm. Mr. Bullock has been engaged in research and development of phenolic and furane resins for application in chemical resistant plant equipment.

•

R. G. Brandes Co. of Houston, Texas, will represent the R. M. Hollingshead Corp. in the Texas-Oklahoma area on the sale of bulk sizes of aviation chemical to the southwest aviation industries. The firm will also represent Hollingshead on the sale of Cocoon products in the Southwest area. This latter process is a method of protecting military tanks and other vehicles going into overseas shipment and storage. Newly promoted to treasurer and secretary of the Hollingshead Corp. is **Joseph L. Laputka. Lloyd L. Entenmann** was made controller and assistant secretary.

•

Appointment of **Harry B. McClure** as executive vice-president of Carbide and Carbon Chemicals Co., a division of Union Carbide and Carbon Corp. was announced by J. G. Davidson, president of Carbide and Carbon Chemicals Co. Mr. McClure has been vice-president since 1944.

•

Sylvania Electric Products Inc. has announced the appointments of **E. Finley Carter** as vice president and technical director of the company and **Howard L. Richardson** as vice president in charge of engineering operations. Mr. Carter has been a vice president since 1945 and Mr. Richardson since 1951.

•

Death of **Sumner Simpson,** 79, board chairman of Raybestos-Manhattan, Inc., was announced recently.

•

Promotions and additions to personnel have been announced by American Wheelabrator and Equipment Corp. In the home office, **Robert L. Orth** was appointed field sales manager. **Julius E. Skene** was advanced to manager of customer service and **Philip R. Jordan** was promoted to chief sales engineer. **Gordon R. Bryant** was promoted to district manager of the Detroit office. **John W. Swantz** joined the Detroit office as district sales engineer, and **Erwin C. Shepard** was added as a service engineer. **F. H. Toman** was appointed to sales engineer in the Chicago office. **J. Douglas Lamb** was appointed district service engineer for the Toronto office. **Wilfred G. Carrie** is now district manager of the Seattle office. **George C. Tolton** has been appointed district manager of the Greensboro, N. C. branch.

•

Harry A. Hauser of Carpenter Steel Company's Alloy Tube Division, Union, N. J., has been appointed a Pacific Northwest sales representative for the firm.

•

Richard C. Martin has been appointed national sales director for Kelite Products, Inc. Mr. Martin started with Kelite in 1944 in charge of the Southern division. He will make his new headquarters at the Kelite main plant, 1250 N. Main St., Los Angeles, Calif.

E. K. Wilkins has been appointed general construction manager of Ebasco Services Inc. Mr. Wilkins will supervise all Ebasco construction activities.

•

Moore F. Floyd has been appointed sales representative in Texas for the Reilly Tar & Chemical Corp. He replaces **Charles L. Slover** who will become associated with Keith-Kote Co., Grand Prairie, Texas. Mr. Floyd, a graduate of Texas A & M, will have his office in Dallas.

•

Reassignment and promotion of three plant managers in preparation for the planned opening of the firm's Sulphur Springs, Texas, plant late this year was announced by the Rockwell Manufacturing Co. **Floyd V. Snodgrass** has been appointed to a special administrative post involving supervision of production and operations at Oakland and Sulphur Springs. Replacing him as general manager at Oakland is **W. D. Willes.** Assuming Mr. Willes former position as general manager at Barberton, Ohio, will be **W. T. Gettig.**

•

Jack W. Harris has been named city salesman by McEvoy Company of Houston.

•

J. Roy Gordon, vice-president and general manager of Canadian operations of The International Nickel Company of Canada, Ltd., has been elected a director of the company.

•

Robert F. Elmiger, formerly statistician and economic analyst for Esso Standard Oil Company has been named sales analyst for Alloy Tube Division, Union, N. J., of the Carpenter Steel Company.

•

Richard J. Murphy has been appointed assistant manager of the foreign department of Pittsburgh Coke & Chemical Co., Pittsburgh, Pa.

•

J. J. Merrill has been named Boston Division salesmanager by A. M. Byers Co., Pittsburgh, Pa.

•

Howard E. Moses, formerly chief engineer and director of the Pennsylvania bureau of sanitary engineering, has been appointed chairman of the Ohio River Valley Water Sanitation Commission.

•

Ray Thomas, a member of the National Association of Corrosion Engineers, has been elected to the board of directors of the Vimasco Corp., Charleston and Nitro, W. Va., according to an announcement by W. A. Pugh, president of the firm. Mr. Thomas has been staff engineer with Carbide and Carbon Chemicals Co., for the past 19 years where he did research, design, engineering, specification and application of thermal insulation for temperature requirements, including elevated, atmospheric and sub-zero ranges. With Vimasco, his main interest will be in the use of coatings. In addition to NACE membership, Mr. Thomas is active in the American Society for Testing Materials, being present chairman of the Research Committee, and past chairman of other ASTM committees. He is credited with founding the Thermal Insulation Society. He is the originator of the Thomas System of Dimensional Standards for thermal pipe insulation and invented the Thomas clip for securing acoustical treatment.

Corrosion Abstracts

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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1. GENERAL

1.6 Books

1.6, 7.10

Pile Foundations; Theory, Design, Practice. Ed. 1. ROBERT D. CHELLIS. 681 p. **1951.** McGraw-Hill, New York.

Provides, in one source, the information required for the design, driving, and maintenance of pile foundations. Describes pile-foundation failures of 60 actual cases, with causes, methods of prevention and remedies. Standard specifications of leading technical societies and associations and of leading manufacturers of piles and piling contractors are given. Numerous figures and photographs.—BLR.

1.7 Organized Studies of Corrosion

1.7.2, 4.6.11, 4.2.5

Corrosion Testing. *Mechanical Engineering,* **74,** 30 (1952) Jan.

Further facilities for the study of sea water corrosion are being added to the Harbor Island Test Station of the Kure Beach project, near Wilmington, N. C., it was announced by F. L. LaQue, in charge of International Nickel Company's corrosion engineering section, under whose supervision the project is operated. Included in the new facilities will be a full sized salt water evaporator and distillation unit to study the effects

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AER—Aeronautical Engineering Review, Institute of Aeronautical Sciences, Inc. 2 East 64th St., New York 21, N. Y.

ALL—The Abstract Bulletin, Aluminum Laboratories, Ltd. P. O. Box 84, Kingston, Ontario.

AWWA—Journal, American Water Works Association, Amer. Water Works Assoc., 521 Fifth Ave., New York 17, N. Y.

BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

BTR—Battelle Technical Review, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.

CALCO—Calco Chemical Division, American Cyanamid Corp. Bound Brook, New Jersey.

CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

CEC—Consolidated Edison Co. of New York, Inc. 4 Irving Place, New York 3, New York.

EL—Electroplating. 83/85 Udney Park Road, Teddington, Middlesex, England.

EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.

INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.

IP—Institute of Petroleum. 26 Portland Place, London W#1, England.

JSPS—Japan Society for the Promotion of Science, Address: Mr. Hayata Shigeno, Secretary, Committee of Preventing Corrosion, c/o Government Chemical Industrial Research Institute, 1-Chrome Nakameguro, Meguro-ku, Tokyo, Japan.

MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.

MI—Metallurgia Italian. Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.

MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.

NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.

NBS—National Bureau of Standards. Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.

NSA—Nuclear Science Abstracts. United States Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.

PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.

RA—Refrigeration Abstracts, American Society of Refrigeration Engineers. 40 West 40th St., New York 18, N. Y.

RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.

RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.

SE—Stahl Und Eisen, Verlag Stahleisen, M. B. H., Dusseldorf, August-Thyssen Str. 1. Postscheck Koln 4110, (22a) Dusseldorf, Germany.

TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.

UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.

ZDA—Zinc Development Association. Lincoln House, Turl Street, Oxford, England.

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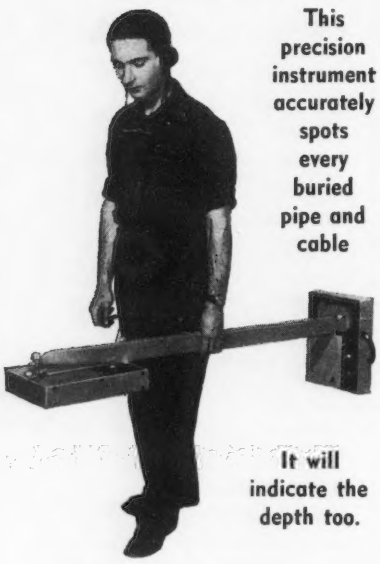

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of water treatment and design on corrosion and scaling of such units, especially as used on board ship. The equipment will include a boiler plant with a capacity of 4,000 lbs. of steam per hr. The new unit will be housed in the present laboratory building at Harbor Island and, to replace the space thus used, a new two-story concrete structure will be erected on the site. The first floor will be used by machine and carpenter shops and for the new boiler. The second floor will provide for a meeting room to accommodate up to seventy-five people as well as a marine museum where specimens of wood, metals and other materials removed from test will be displayed. Additional facilities will be provided for laboratory studies of marine organisms and other biological studies. An enlarged photographic darkroom also will be provided. Concurrent with the erection of the new building at Harbor Island, the facilities for exposure of specimens to sea spray near the ocean at Kure Beach are being extended by a new test lot located about 80 feet from the ocean. This will increase the capacity of existing sea spray facilities approximately three times. During the sixteen years of its existence, the Harbor Island project has tested more than 20,000 specimens in sea water, 25,000 in sea atmosphere and a somewhat smaller number in sea spray. The atmospheric and spray tests are still located at Kure Beach. Specimens studied include metals, wood, rope, and even protective coatings such as paint.—TIME.

2. TESTING

2.3 Laboratory Methods and Tests

2.3.2

The Salt-Spray Test. *Metal Ind.* (London), **80,** No. 7, 123-126 (1952) Feb. 15.

A general discussion of salt spray testing including history, methods, types of apparatus and the effect of a number of variables such as position of specimen and pH of solution. Uses of the test are then discussed; these are primarily for assessing coatings—metallic, organic, or inorganic. One important use is for testing the porosity of cathodic coatings. The limitations of the test are on the whole adequately emphasized, but F. A. Champion points out in a letter (ibid., March 21, 1952, **80,** No. 12, 230) that intermittent spray gives a better correlation with service than continuous spray. —BNF.

2.3.4, 6.2.5, 8.5.3, 8.6.3

Studies of Stainless Steel Used in Pulp, Dye and Bleaching Industries (3rd Report). H. ENDO AND A. ITAGAKI. *J. Japan Inst. Metals,* **16,** No. 6, 352-354 (1952) June.

The immersion corrosion tests were carried out on five kinds of austenitic stainless steel. The specimens were alloys of 20-23% chromium, 20-23% nickel, and small quantity of copper, manganese, silicon, and molybdenum. The corrosives were aqueous solutions of various organic and inorganic acids and salts. Results are as follows: 1) Alloys of 20% chromium—23% nickel—1.4% molybdenum—1.4% copper—3 % silicon —0.5% manganese and 23% chromium—20% nickel—3% copper—3% molybdenum—0.5% manganese showed good acid-resistivities against hydrochloric acid at 27° C. 2) All alloys were not attacked at all in sulfuric acid, nitric acid, acetic oxalic acid, formic acid and aqueous solutions of aluminum sulfate and calcium hyprochlorite. 3) Alloys of 23% chromium—20% nickel—3% molybdenum—3% copper—2% silicon—0.5% manganese and 23% chromium—20% nickel—3% molybdenum—3% copper—0.5% manganese showed good acid-resistivities against boiling. 4) Alloys of 23% chromium—20% nickel—3% molybdenum—3% copper—0.5% manganese, 20% chromium—23% nickel—1.4% molybdenum—1.4% copper—3% silicon—0.5% manganese and 20% chromium—20% nickel—3% molybdenum—3% copper—2% silicon—0.5% manganese were not attacked at all in the mixture of boiling sulfuric acid and nitric acid.—JSPS.

2.3.6, 2.3.9, 2.6

Preparation of Replicas for Electron Metallography. W. J. CRAIG. *Metal Progress* (U. S. A.), **60,** No. 2, 68-71 (1951) Aug.

Thin plastic replicas of a metal surface are made in order to study thin sections of the metal in the electron microscope. These are about 500 A units in thickness. Metal oxide coatings and cast metal films are also used. These are not as successful, for the surface of the specimen is often altered in the process. Steps required in making plastic parlodion replicas of a metal surface are as follows: a) material surface preparation, b) applying and drying the parlodion, c) stripping the parlodion film, and d) shadow casting and hardening the film. The metal surface must not be too rough for the replicas will not readily strip off because of mechanical "keying" with the roughened surface. After electrolytic polishing, a plastic film is formed by flowing a solution of parlodion of proper concentration on the metal surface and allowing it to dry in a vertical position. Moisture breaks the bond of this film and scotch tape is applied over the area, which is covered with a stainless steel grid. This whole is lifted and stripped from the grid and placed on a glass slide for shadow casting. This process increases the differential transmission or absorption of electrons by the replica. The replica is hardened to prevent the film from being split and destroyed by an intense beam of electrons in the microscope. The electron microscope extends the limit of resolution to about 100 A Units.—ALL.

2.3.7, 2.3.6, 5.4.5

Method of Examining the Adhesion of Paint to Steel. S. C. BRITTON and R. M. ANGLES. *J. Iron and Steel Inst.,* **168,** Pt. 4, 358-363 (1951).

A strip of cellulose adhesive tape, which has been pressed firmly on a painted surface, carries with it when it is removed by a snatch-pull, areas of paint that have poor adhesion. A reproducible method based on this fact has been developed to compare paints and methods of preparing steel for painting, by revealing the area of paint loosened by corrosion or by controlled physical damage. Manufacturing operations on coated tinplate have been represented by a cupping test, and the damage suffered by paint coatings in service is represented by parallel scratches made mechanically, and by the impact of a falling weight. In corrosion tests, the method is very suitable for use after

the provisional standard sea-water spray test (BS 1391). Results show the improved paint adhesion obtained by phosphating or tin-plating before painting. Pictures and 7 references are included. —RPI.

2.3.9

Measurement of Properties of Thin Films on Chromium by the Reflection of Polarized Light. J. B. BATEMAN and MARGARET W. HARRIS. *Annals of the New York Academy of Sciences*, **53**, 1064-1081 (1951) July 20.

Results of polarization measurements on aliphatic-acid layers transferred to chromium by the Blodgett method. The data were obtained in order to determine the conditions most favorable to the precise simultaneous measurement of thickness and refractive index. 17 references.—MR.

2.3.9, 2.3.7, 3.2.3

Measurements on the Formation of Thin Tin Films. A. VAN ITTERBEEK, L. DE GREVE, and F. HEREMANS. *Applied Scientific Research*, sec. B, **2**, No. 5, 352-360 (1952).

The films are sputtered in helium or neon gas. Specific resistance and also the temperature coefficient were measured as a function of thickness. The oxidation phenomenon was studied by means of change in resistance as a function of time. Finally the structure of the films was analyzed by means of the electron microscope.—BTR.

2.3.9, 2.3.7, 3.2.3

Measurements on Thin Iron Films. A. VAN ITTERBEEK, L. DE GREVE, and F. HEREMANS. *Applied Scientific Research*, sec. B, **2**, No. 4, 320-324 (1952).

Curves are established for the specific resistance as a function of thickness for iron films obtained respectively by sputtering or condensation in vacuum. The curves obtained with these two techniques are completely different. Electron-microscope and also electron-diffraction pictures of the films are given.—BTR.

2.3.9

Radiography in Engineering L. MULLINS. *Machinery Lloyd* (Overseas Ed.), 24, 69-81 (1952) Feb. 16.

Some of the ways in which radiography may help engineers. General theory and advantages of gamma and X-radiography; also the limitations. Actual working methods.—MR.

2.3.9, 2.3.6, 2.4.3

Methods of Detecting Cracks and Defects on the Surface of Castings by Fluorescence. *Fonderie*, No. 65, 2539-2540 (1951).

The cracks are impregnated for up to 15 minutes with the fluorescent solution washed in warm water and air dried. The solution is driven into the cracks by the application of a very finely divided powder and the surface examined under a mercury lamp.—MA.

2.3.9, 6.2.5, 3.2.2

Analysis of Metallic Sound as a Testing Method—1—Measure of the Intercrystalline Corrosion in 18-8 Stainless Steels. Characteristics Symmetries in the Elastic Moduli. O. MASI AND A. FERRI. *Met. Ital.*, 44, 207-219 (1952).

To measure the extent of the intercrystalline corrosion in stainless steels

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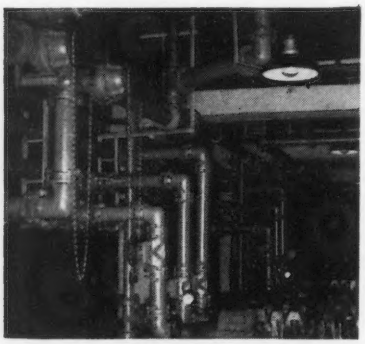

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(18% chromium—8% nickel types) the authors have developed a method based on analyzing, and gathering by means of an oscillographic recorder, the sound emitted by tests bars opportunely struck. Compared with testing means already in use, the one suggested reveals greater sensitiveness. Furthermore the oscillograms obtained allow the singling out of a particular form of symmetry of the parameters of the sound emitted by the rolled test bars, which the authors relate with the existence of a corresponding symmetry in the elastic moduli.—MI.

2.4 Instrumentation

2.4.3, 2.3.9

Radiographic Techniques for Examining Steel Castings. *Foundry Trade J.*, **91**, 731-733 (1951) Dec. 27.

Describes an investigation carried out by members of the non-destructive testing sub-committee of BISRA into the relative merits of a number of radiographic techniques suitable for use on steel castings. Data are tabulated.—BLR.

2.4.3, 2.3.9

New Procedures for Electronic Non-Destructive Testing of Materials. (In French.) D. F. Foster. *Metaux; Corrosion-Industries*, **26**, 497-513 (1951) Dec.

Presents a brief study of the theoretical bases of electronic, non-destructive testing of materials with the aid of Foucault currents (eddy currents). Apparatus is described, diagrammed, and illustrated. Includes charts, sketches, and photographs.—BTR.

2.4.3, 2.3.9

New Methods of Non-Destructive Testing and Their Basic Principles. F. Foster. *Metall*, **5**, Nos. 1-2, 20-21 (1951).

Foster gives brief notes of methods based on chemical impregnation, acoustics, thermal conductivity, electrical resistivity, and electromagnetic induction. —MA.

3. CHARACTERISTIC CORROSION PHENOMENA

3.1 General

3.1, 4.1, 5.1

Causes and Prevention of Corrosion. Arthur Marsden. *Gas J.* (London), **269**, 413, 414+ (1952) Feb. 13.

Contact of dissimilar metals; non-uniformity of the metal, whether due to impurities or to segregation; presence of oxygen in the surrounding medium; internal stresses in metals; stray electric currents, which often assist in the destruction of gas and water mains; and elevated temperatures are discussed as factors in the above. Various forms of protection are cited.—BTR.

3.2 Forms

3.2.2, 3.4.6, 2.3.4

Relative Importance of Various Sources of Defect-Producing Hydrogen Introduced Into Steel During Application of Vitreous Coatings. D. G. Moore, M. A. Mason, W. N. Harrison. Nat'l Bureau of Standards. *J. Am. Ceramic Soc.*, **35**, No. 2, 33-41 (1952) Feb. 1; National Advisory Committee for Aeronautics, Technical Note No. 2617, 11 pp. 1952, Feb.

Purpose of the investigation was to study and determine experimentally the relative importance of various sources of defect-producing hydrogen introduced into steel during the application of vitreous-type ceramic coatings. Under the conditions investigated, the principal source of defect-producing hydrogen was the dissolved water present in the enamel frit of the coating. Acid pickling, milling water, chemically combined water in the clay and quenching water were all minor sources. Test results indicate that fish-scaling, reboiling and possibly primary boil may be eliminated by using a coating prepared with a water free frit. 20 references, tables, graphs, photographs. —INCO.

3.2.2, 6.4.2, 3.8.2, 3.8.4

Views on the Mechnaism of Pitting Corrosion of Aluminum. P. M. Aziz. Paper presented January 29, 1952, at Ottawa, Ontario to the second annual joint meeting of the Physical Chemistry Division of the Chemical Institute of Canada and Associate Committee on Corrosion Research and Prevention, of the National Research Council of Canada. *Corrosion*, **9**, No. 3, 85-90 (1953) Mar.

1. Thermodynamic calculations have been carried out to determine the possible corrosion reactions of aluminum in neutral and near neutral aqueous solutions and the domains of stability of the various corrosion products. 2. The quantitative electrochemical factors determining the corrosion rate are discussed. 3. A qualitative mechanism for the initiation and propagation of a corrosion pit in aluminum is discussed.

3.2.3, 3.8.4, 4.6.1

Wetting of Metals by Water. J. L. v. Eichborn. *Werkstoffe u. Korrosion*, **2**, No. 6, 212-221 (1951).

Previous work on the wetting of metal surfaces by water is reviewed, together with the results of some original investigation by v. Eichborn on the wetting of mercury. The following points, in regard to silver, gold, copper, mercury, nickel, platinum, zinc, and brass, are discussed at length: 1) the relationship between wetting and free boundary-surface energy, 2) advancing and receding contact angles between water/metal and water-air/metal surfaces, 3) surface tension and heat of adsorption as measures of the adsorptive power of metal surfaces. It is suggested that wetting hysteresis and the firm adherence of residual traces of water are the result of the metal surface retaining adsorbed OH_3^+ or OH^- ions. 33 references.—MA.

3.3 Biological Effects

3.3.4, 4.5.1, 1.3

The Present Status of Bacterial Corrosion Investigations in the United States. Carl G. Deuber. Deuber Laboratories, New York, New York. *Corrosion*, **9**, No. 3, 95-99 (1953) Mar.

Since the first studies with bacterial corrosion of underground pipe lines in 1939 in the United States, chief interest has been centered in this subject in the Eastern states. Indications are that the causative sulfate-reducing bacteria and the characteristic anaerobic soils associated with their corrosive action are actually widely distributed. Various reasons

are suggested for the limited interest in bacterial corrosion. Salient features useful for the detection of bacterial corrosion are described and preventive measures are discussed.

4. CORROSIVE ENVIRONMENTS

4.2 Atmospheric

4.2.3, 6.2.3, 4.3.2

1 The Corrosion of a Steeel Surface by Condensed Films of Sulphuric Acid (from Flue Gases); 2 The Influence of Carbon Smokes on the Corrosion of Metal (Steel) Surfaces Exposed to Flue Gases Containing Sulphur Trioxide. 1 by D. FLINT AND R. W. KEAR; 2 by R. W. KEAR. *J. Applied Chem.* (London.) **1,** No. 9, 388-393; 393-399 (1951) Sept.

1 The corrosion rate increased with increasing sulfuric acid dewpoint; for gas of constant dewpoint, corrosion was a maximum when the surface temperature of the steel was 20°-45°C below the dewpoint. **2** At low smoke concentrations there was an increase in corrosion at temperatures just below the dewpoint, but with greater smoke concentrations corrosion was substantially reduced; the carbon appears to reduce the sulfur trioxide concentration of the gases by adsorption.—BNF.

4.3 Chemicals, Inorganic

4.3.7, 7.5.5, 5.8.2, 6.6.5, 5.4.3

Sodium Chlorate . . . How to Handle it Safely. R. MATTAIR, Oldbury Electro-Chemical Co. *Paper Industry,* **33,** No. 10, 1187-1188 (1952) Jan.

Hazards, properties, precautions in handling and storage of sodium chlorate are discussed. Nickel and type 304 or 316 stainless steel are suitable for tanks, pumps and lines. Type 2S Al, used in pipe lines and in filter presses, is quite satisfactory, although it is subject to electrolytic corrosion and must be protected with non-conductors such as rubber or Bakelite. Ordinary steel or cast iron tanks are more subject to corrosion, particularly in the case of open tanks with fluctuating liquid levels. Life of such tanks is lengthened by addition to the chlorate solution of 500 parts per million of sodium dichromate and 10-20 parts per million of sodium silicate. Steel tanks lined with silica-aggregate concrete have given long service, although some cracks do develop in the concrete. None of the rubber or plastic compositions tried were considered satisfactory for tank linings, since all tend to become brittle or to be attacked.—INCO.

4.4 Chemicals, Organic

4.4.5, 7.6.9, 6.3.10

Organic Fluorides. XII. A Simple Rotating Reactor for Fluorination. W. E. MASSINGHAM, R. MONTGOMERY, F. SMITH, AND B. R. J. THOMAS. *J. Applied Chem.* (London), **2,** Pt. 4, 221-224 (1952) April.

Relatively simple rotating reactor is described for the fluorination of hydrocarbons and their derivatives. The reactor consisted of a horizontal copper tube with the whole of the reactor space

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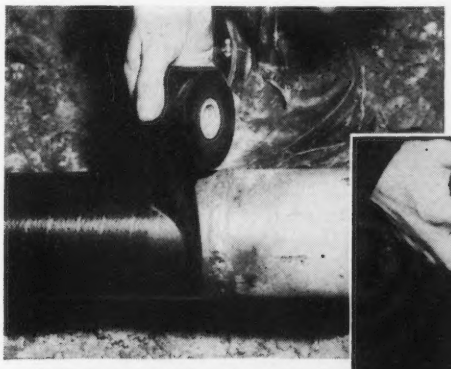

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being swept by 3 nickel paddles mounted on a nickel shaft that was coaxial with the reactor tube. When the protective film of copper flouride was removed exposing fresh surfaces of copper, the corrosion rate was high. This rate was greatly reduced by using nickel. For the same reason the shaft originally made of steel was replaced by one of nickel. Diagram, table and 9 references are given.—INCO.

4.5 Soil

4.5.1, 6.5

Symposium on Corrosion of Buried Metals. Symposium before Iron & Steel Inst., Brit. Iron Steel Research Assoc. and Corr. Group of Soc. Chem. Ind., (London), Dec. 12, 1951. *Foundry Trade J.*, **91**, No. 1842, 717-720 (1951) Dec. 20.

Papers include: 1. "Test on the Corrosion of Buried Iron and Steel Pipes." J. C. Hudson and G. P. Acock; 2. "Investigaitons on Underground Corrosion." K. R. Butlin, W. H. J. Vernon and L. C. Whiskin; 3. "Cathodic Protection." K. A. Spencer; 4. "Cathodic Protection of Buried Metal Structures." R. de Brouwer; 5. "Corrosion of Buried Copper and Ferrous Strip in Natural Salted Soils." G. Mole; 6. "Tests on the Corrosion of Buried Aluminum, Copper and Lead." P. T. Gilbert and F. C. Porter.—INCO.

4.5.2, 1.7.1, 7.2, 5.1

Corrosion of Buried Metals. *Metallurgia*, **45**, No. 267, 23-28 (1952) Jan.

A report of the proceedings at a symposium held in Dec. 1951 by the Iron and Steel Institute, the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry. J. C. Hudson had shown in recent tests that 2 oz./sq. ft. zinc coatings protected cast iron pipes for at least five years when buried in a salt marsh, London clay, moist neutral clay and Keuper marl. Corrosion was severe in cinders. The behavior of other protective coatings in similar soils is described. Two papers dealt with cathodic protection, in which the necessary current was derived either from a generator or a buried anode, e.g. of zinc. These methods were said to be complementary to the provision of a protective coating.—ZDA.

4.7 Molten Metals

4.7, 3.6.5

Experimental Confirmation of Electrochemical Theory of Liquid Alloys in the Iron-Carbon-Silicon System. (In Russian.) O. A. Esin and L. K. Gavrilov. *Bull. Acad. Sci. U. R. S. S.* (Izvestiia Akad. Nauk SSSR) Section of Technical Sciences, **1951**, 1234-1242, Aug.

The emf's. developed between pairs of molten alloys of the above system were determined. The data are discussed, tabulated, and charted for alloys containing 0.65-43.0% silicon and 0.20-4.48% carbon.—BTR.

5. PREVENTIVE MEASURES

5.1 General

5.1, 4.1

Chemistry Research 1950 (Work on Corrosion.) Chemical Research Laboratory. Brochure, 1951, 104 pp. His Majesty's Stationery Office, London, 3s. 6d.

The corrosion section of this report of work at the Chemical Research Laboratory in 1950 includes immersed corrosion (steel in moving conditions, electrochemical studies of painted steel, organic inhibitors, boiler tubes, buried metals), surface films, atmospheric corrosion (including coatings and inhibitors), and studies of sulphate-reducing bacteria.—BNF.

5.2 Cathodic Protection

5.2.1, 5.4.5, 8.9.5

Behavior of Shipbottom Paints Subjected to Cathodic Protection. R. P. Devoluy. A paper presented at the Eighth Annual Conference, National Association of Corrosion Engineers, Galveston, Texas, March 10-14, 1952. *Corrosion*, 9, No. 1, 2-10 (1953) Jan.

This paper discusses the results of a test program designed at a meeting of interested parties held at the Sea Horse Institute, Harbor Island, N. C. on June 8, 1950. The principal object of the investigation was to determine whether cathodic protection can be applied to operating ships without inactivating anti-fouling paints in the manner frequently observed when certain anti-fouling paints are associated with areas of bare steel or zinc. Secondary objectives concerned the effects of variations in the composition of the paints used and in variations in the dried film thicknesses of the anti-corrosive paints used in the paint systems.

Several variations of two basically different types of ship bottom paint systems were studied for inactivation of the anti-fouling paint by cathodic protection. In general, it was found that ship bottom paint systems which can be expected to inactivate, and hence foul without cathodic protection, are the same paints that will be inactivated in a relatively short time by protective currents. The importance of the anti-corrosive undercoats in preventing inactivation is stressed for it was found that both cases of inactivation observed in this test were substantially eliminated by a better "barrier" coating between the anti-fouling paint and the steel plate. Paints of low permeability and good alkali resistance materially reduced the current requirements for protection.

The most important observation made in this test program was that the current density should be controlled by limiting the potential to the minimum necessary for the protection of the steel. This was not done in this preliminary investigation and hence almost all the coatings were severely damaged by the effects of the unnecessarily high currents.

5.3 Metallic Coatings

5.3.2

On the Formation and the Properties of the Antimony Coating by a Special Cementation Method. Hirokichi Kanayama. *J. Japan Institute of Metals*, **16**, No. 2, 100-104 (1952), Feb.

It was found that the metallic coating of antimony was formed of antimony powder by a special cementation method. This method is to pack the iron in the powder composed, by volume percentage, of 30% antimony, 30% zinc oxide, 30% carbon and 10% sodium carbonate, and heat it as 550°-650° for 30-60 min-

utes. The author postulates that the coating is formed by the solid diffusion and the gaseous penetration of antimony into iron. The effects on the nature of coating produced by a sort of powder, antimony contents in the powder (from 10% to 90% antimony), heating temperature (from 400° to 800°) and heating time (from 0.5 to 4 hr.) were studied. The coating consists of two layers: 1) The outer layer, that forms the greater part of the coating, consists of antimony containing, in the state of solid solution, a small amount of iron and 2) the inner layer which consists of iron-antimony metallic compounds. The inner layer was not formed by heating below 630°. The total thickness of the coating was about 0.02 mm, when heated at 600° for 30 minutes. The cohesion of the coating was tested by measuring the difference of weight after striking the specimens with iron plate or rubbing them with carborundum powder. The stability of the coating depends upon the thickness of the inner layer. It was the greatest when heated at 650°. The thickness of inner layer at that time was very small. The corrosion of the coating in 10° hydrochloric acid, 10% sulfuric acid, 10% nitric acid and 2% sodium chloride in aqueous solution and that in the air were also examined.

Merits of this method are as follows: 1) Apparatus and technique for it are very simple. 2) The coating has a beautiful silver lustre. 3) The cohesion of the coating is superior to that by electroplating. A grave defect is that the coating is relatively brittle.—JSPS.

5.3.2, 2.2.2, 2.3.2

Tin-Zinc Plate Protects Steel Bolts in Aluminum Structures. *Materials & Methods,* **35,** No. 5, 196 (1952) May.

An 80-20 tin-zinc alloy plate is the best protection for steel bolts used in aluminum structures according to tests conducted at the Fulmer Research Institute in England. Laboratory and field tests were conducted on sherardized, zinc plated, black oxide finished, cadmium plated, phosphate coated and tin-zinc alloy plated steel bolts. One set of specimens of each coat was exposed to one of the following: 3 percent salt spray; humid sulfur dioxide atmosphere; marine atmosphere; and industrial atmosphere. In every case the zinc-tin alloy coatings protected the bolts and gave rise to the minimum amount of corrosion of the aluminum. Zinc coatings gave the next best performance, protecting the steel with slight attack of the aluminum.—ALL.

5.3.2, 2.3.2

Short-Time Testing of Electrolytic Chromium-Nickel Coatings for Corrosion Resistance. (In German.) HERMANN HEFELE. *Metalloberflache,* Ser. B, **4,** B17-B24 (1952) Feb.

Compares atmospheric corrosion with results of various accelerated corrosion tests. Describes porosity tests, and discusses causes of corrosion; increasing pores, blisters, and cracks in chromium-nickel electrodeposits. Photomicrographs, tables, diagrams, and graphs are presented. 21 references.—BTR.

5.3.2, 3.8.3, 5.9.4

The Passivation of Tinplate (Against Corrosion). W. EILENDER. *Werkstoffe u. Korrosion,* 2, No. 8, 289-292 (1951).

A report of a study of the effects of various solution treatments on the properties of hot-dipped and electrolytically coated tinplate. The results show that

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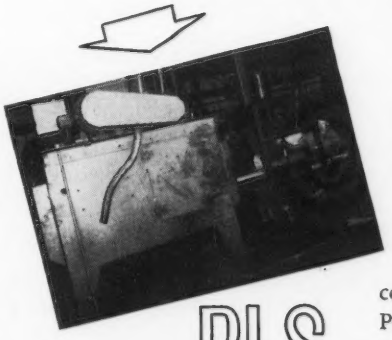

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the corrosion-resistance is greatly enhanced by simple immersion for 30 seconds or cathodic treatment for a few seconds in a solution containing crystalline tribasic sodium phosphate 10, crystalline potassium dichromate 8, and sodium hydroxide 20 g./1., together with a few grams of an organic sulphonate as wetting agent. Following such treatment the tinplate is neither discolored, nor does corrosion start from the pores, after 1) immersion for several hours in hydrogen sulfide containing water at 60°C, or 2) heating for 15-20 minutes at 200°C.—MA.

5.4 Non-Metallic Coatings and Paints

5.4.5

Air-Drying Plastic Protective Coating. *Engineers' Digest,* **12,** No. 5, 142 (1951) May.

A new air-drying plastic protective coating has been developed which can be used to protect tanks, tank cars, pipes, fittings, structural steel parts and chemical processing equipment against attack by splash, drip and spray from corrosive chemicals, corrosive atmospheres, weathering and rust. This plastic combines high film flexibility with good adhesion and impact resistance. It is claimed that this plastic will not chip or crack and that it can be used on steel, aluminum, concrete, hardwood, or composition board. It is applied by spray, allowing 1 hour drying time between coats and 24 hours drying time after the final coat. It requires no primer and can be produced in a variety of colors. The coat retains its flexibility throughout its service life. A sharp instrument will cut through the film, but the break can be repaired easily by touching up with brush or spray. Metal should be grit or sand-blasted before the coating is applied, cement should be etched with HCl, while wood and composition board needs rough sanding to assure good bond.—INCO.

5.4.5, 1.7.1, 2.5

ASTM Standards on Paint, Varnish, Lacquer and Related Products. September, 1952. 6 x 9, paper bound, 781 pages plus XIX. American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa. Per Copy $5.75.

The eighth edition of the compilation of ASTM standards on paint, varnish, lacquer and related products provides more than 200 specifications, tests and definitions issued by ASTM Committee D-1. Related standards from other committees are included also. Material covered includes specifications for pigments, drying oils, paint driers, thinners, shellac, varnish, naval stores, lacquer and lacquer materials, traffic paint, bituminous emulsions, paint tests, putty and paint weathering tests. Of the 23 new standards included, 16 are methods of test, six are specifications and one covers forms for reporting results of exposure tests on paint.

5.4.5, 4.4.6

Preliminary Report on Effect of Spillage on Hot-Applied Coal-Tar Coatings. CARL MILLER. *Oil Gas J.,* **50,** 294-295 (1952) Mar. 17.

States that spillage of petroleum products has little effect on narrow-range enamels; wide-range enamels are not satisfactory. Relates the effect of gasoline, kerosene, and fuel oil on hot-applied, coal tar enamels used for protection against corrosion.—BTR.

5.4.5, 5.4.8

B.S.R.A. Resistance Experiments on the (Ship) *Lucy Ashton.* **I—Full-Scale Measurements.** M. E. DENNY. International Conference of Naval Architects and Marine Engineers, 1951. *J. Brit. Shipbuilding Res. Assoc.,* **6,** No. 7, 359-360 (1951).

Use of bituminous paint, as compared with red oxide paint, reduced resistance to motion by about 3½%. An increase of about the same amount, due to slime formation, was found after laying up for 40 days.—RPI.

5.4.5, 8.3.5

Phenolic Resin Anti-Corrosive Coatings. F. G. ESTARTUS. *Rev. plasticos* (Madrid), **2,** Nos. 7 & 9, 23-26+, 114-115+ (1951).

The physical chemistry of phenolic resin stoving lacquers, e.g., for food containers, is discussed in terms of concepts of mobility and structure. A comprehensive table summarizes the possible defects of such lacquers, the physico-chemical causes leading to such defects and how they may arise from factors involved in the manufacture of the resin or the manufacture or application of the lacquer. The preparation of the metal surface and the stoving of a 3-coat system are described in detail. The effect of replacing phenol in resoles by o-cresol (10-100%) on the chemical resistance of the films has been examined. High proportions of o-cresol considerably reduce the resistance to 10% sulfuric acid and acetone and not > 30% could be incorporated without serious impairment.—RPI.

5.4.5, 8.3.5, 6.4.2, 8.3.3

Ethoxyline Coating Protects Aluminum. *Modern Plastics,* **29,** No. 6, 160 (1952) Feb.

An ethoxyline coating has been used to render the inner walls of an aluminum container used in a cream whipping unit impervious to the action of the fatty acids in the cream contents. The aluminum container is filled with the liquid resin and the excess is poured out after a short interval. The resin which adheres to the inner surface of the bottle hardens to form the coating. The coating, as well as protecting the container from corrosion, simplifies cleaning operations.—ALL.

5.6 Packaging

5.6.3, 1.2.4, 6.4.2

Preserving Tanks and Trucks With Aluminum Foil. *Modern Metals,* **8,** No. 2, 46-49 (1952) Mar.

Army vehicles are being sealed in aluminum foil to prevent corrosion during storage and shipment. A thoroughly mixed bituminous mastic is applied by brushing around openings and parts that are to be sealed. The aluminum foil is then applied by firmly embedding it in the adhesive mastic and moulding it to the shape opening. Finally, an aluminum paint coating is brushed over the entire surface of the aluminum. A ventilator and rain plug opening are employed to prevent condensation within the vehicles. Interior compartments of vehicles for export shipment are protected by desiccants and all exposed aluminium foil seals and closures are painted with lus-

treless OD paint just before shipment.—ALL.

5.6.3, 5.8.4, 6.6.4

Coated Papers Inhibit Corrosion. *Machinist*, **96**, No. 14, 506 (1952) Apr. 5.

Account of new packaging technique in which papers are impregnated with V. P. I. (Vapour Phase Inhibitor), developed by the Royal Dutch-Shell group, which vaporizes and inhibits the corrosion of steel and aluminum articles in moist atmospheres.—BNF.

5.7 Treatment of Medium

5.7.6

Demineralization Including Silica Removal by Ion Exchange. The Permutit Company, 330 West 42nd St., New York 36, New York. Bulletin No. 3803. (1952) 28 pp. 8½ x 11 inches. Paper bound.

Describes ion exchange principles and equipment, design features, recommendations and specifications.

5.8 Inhibitors and Passivators

5.8.2, 2.3.4, 4.6.2

A Laboratory Method for the Study of Steam Condensate Corrosion Inhibitors. HAROLD PATZELT. National Aluminate Corp., Chicago, Ill. A paper presented at the Eighth Annual Conference, National Association of Corrosion Engineers, Galveston, Texas, March 10-14, 1952. *Corrosion*, **9**, No. 1, 19-24 (1953) Jan.

A laboratory method for studying corrosion in steam condensate systems is described. In brief, a synthetic condensate is produced in a glass tower by aerating heated distilled water with a mixture of carbon dioxide and air. This condensate and a solution of the treatment are proportioned into a test container by gravity feed. A number of steel test coupons are suspended in the latter and the liquid is mildly agitated with a paddle stirrer. At periodic intervals a specimen is removed from the bath and the weight loss determined. The temperature, free carbon dioxide and dissolved oxygen of the synthetic condensate, and the treatment concentration are controlled throughout the test.

Corrosion test data are presented for synthetic condensate systems in which sodium hydroxide, sodium polyphosphate and neutralizing and film forming amines are used, the effect of precorrosion of the test specimen and of contamination of the condensate with boiler water on the functioning of several types of inhibitors are described.

The merits and limitations of the test method and possible interpretations of certain of the results are discussed.

5.8.2, 5.6.1

Vaporizing Film of Crystals Acts as Corrosion Inhibitor. *Machinery* (N. Y.), **58**, No. 5, 186 (1952) Jan.

Cor-In, a rust preventive, forms an adherent film of crystals that vaporizes and acts as a neutralizing agent, destroying the corrosive effect of all moisture or water vapor that comes in contact with it. Cor-In is applied by brush, spray or dip and after application, the part is wrapped or covered. Dev. by the Organic Products Co.—INCO.

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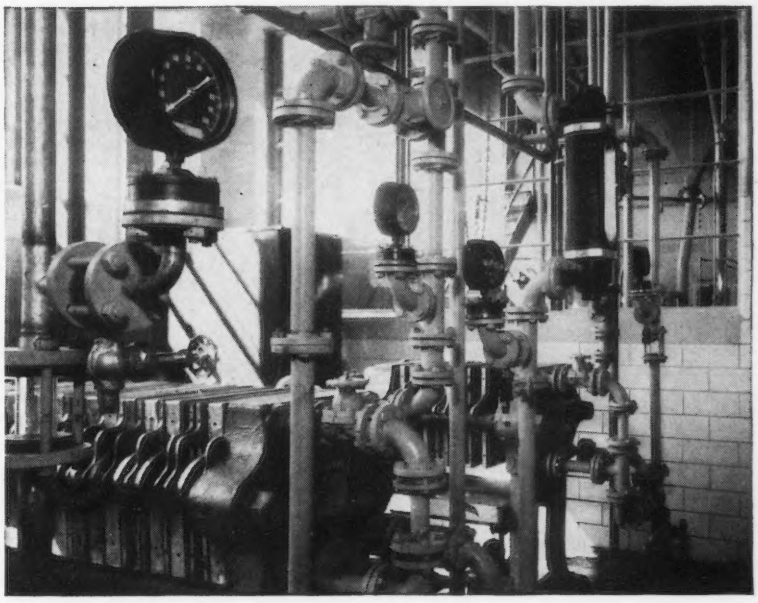

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5.8.3

The Adsorption on Metal Surfaces of Long Chain Polar Compounds From Hydrocarbon Solutions. S. G. DANIEL. *Trans. Faraday Soc.*, **47**, 1345-1359 (1951) Dec.

In studies of the above with certain metals, notably copper, lead, zinc, and cadmium, the isotherms could not be determined because of reactions between the acid and oxide films on the metal surface. In general, ease of adsorption increases with increasing chain length and, for a given chain length, the acid is most strongly adsorbed and the ester least, with the alcohol intermediate. The influence upon adsorption of other factors such as temperature and solubility is discussed. In some cases it was possible to calculate free energy and heat of adsorption. Data are graphed. 17 references.—BLR.

5.8.3, 2.3.9

Radiometric Study of the Adsorption Characteristics of Stearic Acid. STANLEY L. EISLER. *Corrosion*, **9**, No. 3, 91-94 (1953) Mar.

A radiometric test method to measure the amount of adsorption of polar organic rust inhibitors was developed and is described. The choice of stearic acid for this initial work was made because of its known adsorption characteristics. The effect of several variables on the amount of adsorption was also studied. These variables included time of immersion, agitation vs. quiescent immersion, drainage time and temperature, and concentration. It was found that the amount of stearic acid absorbed increased with time of immersion, when coupons were agitated as compared to quiescent immersion and with increased stearic acid content in the solution. The amount of stearic acid adsorbed was found to be independent of the drainage time and temperature. The results of this work indicate that the method may be extended to the study of the adsorption characteristics of petroleum sulfonates and other corrosion inhibitors.

5.8.3, 3.8.2

The Influence of Inhibitors Upon Electrochemical Processes on Metallic Surfaces. (In German.) H. FISCHER. "International Committee on Electrochemical Thermodynamics and Kinetics; Proceedings of the 2nd Meeting" (Libreria Editrice Politecnica Cesare Taburini, Milan, Italy), 1951, p. 105-115; disc., p. 115-116.

Defines inhibition of electrode surfaces, and it's various consequences such as polarization, negative catalysis of resulting reactions, reduction and oxidation of inhibitors, and modefication of the crystallization process. The specific susceptibility of the metal atoms to inhibitors is indicated; and its variation in the submicroscopic realm of the crystals is discussed. Tables and graphs. 11 references.—BTR.

5.8.3, 3.8.2, 4.7, 3.8.4

The Significance of Inhibitors and Poisons in the Study of Electrochemical Processes at Metal (Liquid) Interfaces. HELLMUT FISCHER. *Z. Elektrochem.*, **55**, No. 2, 92-97 (1951).

Fischer briefly discusses: 1) the effect of inhibitors upon concentration, blacking, crystallization, poisoning, and transport-overvoltages in electrochemical processes; 2) the reduction and oxidation of inhibitors; 3) inhibitor sensitivity; 4) the mechanism of the coating of electrode surfaces by an inhibitor due to current flow; and 5) changes in the course of crystal growth. The presence of inhibiting centers (and current density) affects not only the form and orientation of crystal deposits, but produces also corresponding changes in the subcrystallites of the crystal mass. Changes of inhibition produce different forms of crystal growth. Thus, very weak inhibition favors the production of field-oriented sub-crystallites and isolated aggregates of these sub-crystallites growing parallel to the lines of current flow (the so-called field-oriented isolation type of crystallites, F.I.). Weak inhibition by furthering growth in breadth and checking formation of nuclei favors formation of the basal-oriented reproduction type of crystal (B.R.). Conditions for the production of field-oriented prisms, plates, needles, etc., the so-called field-oriented texture type (F.T), and the non-oriented dispersion type (U.D.) of crystals are briefly referred to. 22 ref.—MA.

5.8.3, 4.4.7

Surface Chemical Phenomena in Lubrication. J. E. BROPHY AND W. A. ZISMAN. *Annals of the New York Academy of Sciences*, **53**, Art. 4, 836-861 (1951) June.

Discusses structure and mechanical properties of monolayers of amphipathic molecules adsorbed on metals; and surface chemical reactions of polar compounds with common metals. Data for specific compounds adsorbed on different metals and metal powders are presented and discussed. Rust-inhibitive properties are also considered. 4-ball-tester wear curves for steel on steel using different lubricants are also presented.—BLR.

5.9 Surface Treatment

5.9.2, 6.4.4

Cleaning of Magnesium Surfaces with Alkaline Detergents. *Materials and Methods*, **35**, No. 2, 186, 188 (1952) Feb.

Sodium hydroxide, trisodium phosphate, tetrasodium pyrophosphate, Calgon, Quadrafos and other types of sodium silicate are being investigated as cleaners for magnesium castings. The tetrapyrophosphate and other polyphosphates used as a soak, and electrolytic cleaners caused discolouration of the metal and corrosion. The inclusion of proper amounts of sodium metasilicate with the tetrapyrophosphate eliminated all attack upon the metal.—ALL.

5.9.4

The Chromizing Process, Parts I and III. FELIX BARBAS. *Usine nouvelle*, **7**, No. 35, 23, 25, 27; No. 36, 29, 30; No. 37, 29, 30. (1951).

A review of chromium-diffusion processes, covering reasons for the choice of chromium as a protective metal, the mechanism of metallic diffusion, powder and gas chromizing techniques, and the advantages of the treatment.—MA.

5.9.4

Corrosion Protection by Cold Phosphating; Russians Claim to Have Improved Process. *Chemical Age*, **65**, 295-296, 300 (1951) Sept. 1. [Based on article by V. S. LAPATUKIN in Zhurnal Prikladnoi Khimii *(Journal of Applied Chemistry)*, **24**, 373-382 (1951) Apr.]

Gives details of above process claimed to be superior to those developed in other countries. 14 references.—BLR.

5.9.4

Substitute Finishes for Electroplating: Phosphate Coatings. ALFRED DOUTY. *Plating*, **38**, No. 10, 1030-1033 (1951).

A review of the nature and properties of phosphate coatings on iron and steel, zinc, cadmium, aluminum, and their alloys. Information is included on methods of application, coating weight, time of treatment, salt-spray resistence.—MA.

6. MATERIALS OF CONSTRUCTION

6.3 Non-ferrous Metals and Alloys—Heavy

6.3.4, 3.5.9

Industrial Applications of Stellite. B. J. MACKENZIE. *Canadian Metals*, 15, No. 3, 48+ (1952) Mar.

Stellite, containing approximately 65 cobalt, 25 chromium, 10 tungsten, and 1-2.5 carbon, has high wear and corrosion resistance, is more resistant to erosion than nitrided steels, and keeps its hardness up to 1800°F. Under specific conditions of strength, temperature and type of acid, some grades of Stellite are more corrosion resistant than stainless steels. It is used for planing operations on cast irons, steel castings and fabricated steel components. Stellite cutting tools take heavier feeds. The advantages of hardfacing with Stellite are given. High carbon or high alloy steels can be stellited if the part is uniformly heated during the operation. Austenitic 18-8 makes an excellent base for a stellite deposit. Illustrations.—INCO.

6.3.5, 4.4.3, 4.4.4, 4.3.6, 4.4.2

The Corrosion-Resistance of Stainless Steels Towards Citrus Fruit—Squash Concentrates and Towards Citric Acid–Sugar—Common Salt—Sulphur Dioxide Solutions. J. M. BRYAN AND J. W. SELBY. *J. Sci. Food Agr.*, **2**, 359-364 (1951) Aug.

Results of experiments show that stainless steels containing 2-3% molybdenum have a markedly greater resistance to corrosion by above solutions in general. Welding tends to lower the corrosion-resistance of the molybdenum bearing stainless steel to citrus-fruit concentrates. Data are tabulated and graphed.—BLR.

6.3.5, 8.8.1, 8.5.3, 8.4.3

Developments in the Use of Stainless Steel. J. L. COTSWORTH. *Iron & Steel Engineer*, **28**, No. 11, 66-68 (1951) Nov.

Discussion of stainless steels for use in basic industries such as chemical process plants, paper mills, oil refineries and steel mills. These industries find stainless steel justifies its higher initial cost. The groups containing high nickel contents are most popular.—INCO.

6.3.6, 3.7.2

Newly Developed Bronze Alloys Feature Anti-Galling and Corrosion Resistance. JOHN P. MEYER. *Western Metals*, **10**, 35-36 (1952) Mar.

Describes two new types of the above developed by Olds Alloys, Los Angeles; a white bronze of the chromium-nickel-molybdenum type; and a nickel bronze

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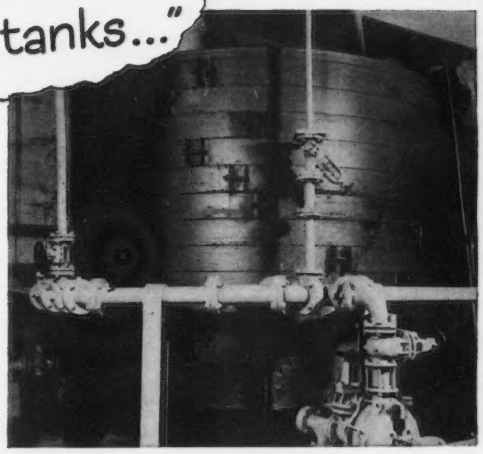
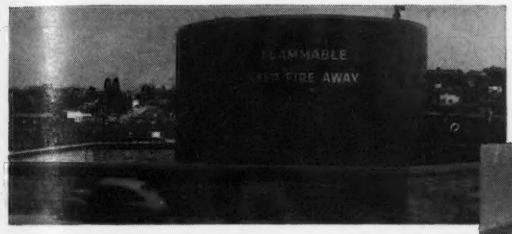
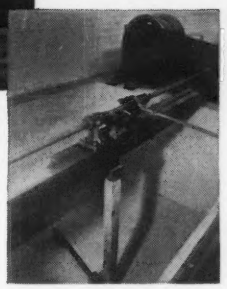


WOOD vs. FERRIC CHLORIDE. To the right is one of two 3500-gallon ferric chloride storage tanks in the Vacuum Filter Plant, Back River Sewage Works, Baltimore, Md. This chemical is used to release moisture from the sludge before it goes into the vacuum filter. The tank is made of wood, with a rubber liner. Outside finish consists of three coats of red Rubalt RA paint based on Parlon, made by Alfred Hague & Company, Brooklyn, N. Y. This paint is the only one found to date which can withstand ferric chloride—a chemical so strong that it will quickly eat away bare metal or concrete.



METAL vs. SALT WATER. The oil storage tank shown above, belonging to Diesel Oil Sales Company, Seattle, Washington, is painted with a green Parlon-based finish, two coats. After two years of exposure in a location almost right on a salt-water bay, the finish is still like new. Paron paint based on Parlon made by Petro Paint Company, a subsidiary of Rudd Paint & Varnish Co., Seattle, Wash.



CONCRETE vs. ALUM. Concrete tank (left) in Water Filter Plant, Celanese Corporation of America, Belvidere Plant, is painted with Torex enamel based on Parlon. Alum solution in the tank was eating through concrete and loosening mortar in the brick wall prior to application of Torex enamel. This Parlon-based finish has now been on the tank nine months. It is in excellent condition, and has substantially simplified and speeded maintenance procedures. Torex enamel, based on Parlon, is made by Inertol Co., Inc., Newark, N. J.

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of unusually high lead content. Properties and applications are discussed.—BTR.

6.3.6, 3.7.2, 1.3

The Corrosion-Resistance (and Other Properties) of Aluminum Bronzes. ERICH FRANKE. *Werkstoffe u. Korrosion,* **2,** No. 8, 298-307 (1951).

A review of the structure, melting, castings, working, mechanical and corrosion-resistance properties, and the application of aluminum bronzes, which may contain small additions of iron, manganese, nickel, lead, and tin to improve their properties for specific purposes. 45 references.—MA.

6.3.6, 5.9.2

Pickling of Aluminum Bronze. *Foundry Trade J.,* **91,** No. 1827, 291 (1951) Sept. 6.

This process, compared with that used for ordinary copper alloys is made more difficult because of the presence of aluminum. A number of laboratory tests have been carried out, the usual method embracing chemical treatment, rinsing in cold running water and drying with rags. A table gives the experimental conditions (composition of bath, temperature and time of immersion) and the finished surface appearance for the chemical treatment. In the case of castings showing porosity or of which the design carries narrow recesses, rinsing in cold running water can be usefully followed by immersion in a bath made up of 5 gm. anhydrous sodium carbonate dissolved in a liter of water. The neutralizing action opposing traces of acid retained by the castings adds to the speed of drying of the castings.—INCO.

6.3.6, 1.3, 3.7.1

Wrought Copper and Copper-Base Alloys. C. L. BULOW. *Ind. and Eng. Chem.,* **43,** 2218-2226 (1951) Oct.

Reviews the literature, providing a considerable amount of information regarding: alloy compositions, specifications, mechanical and physical properties, fabrication properties and techniques, and corrosion resistance of copper and copper alloys under a wide variety of conditions. This information should aid in the use of copper and its alloys so that they will be applied in a manner that will take full advantage of their properties. 162 references.—BLR.

6.3.6, 4.3.2, 2.3.4, 3.8.4

Solution of Copper in Nitric Acid. Parts II and III. (In German.) T. G. OWE-BERG. *Z. anorg. u. allgem. Chem.,* **266,** 118-139 (1951) Oct.

Describes, in Part II, studies on the solubility rate of copper in different concentrations of nitric acid at temperatures ranging from —10° to +30°C. The experiments described in Part III were made with the specimen immersed in nitric acid in different ways as well as without stirring the acid. Data are graphed and tabulated. 21 references.—BLR.

6.3.11, 8.8.1

New Constructional Material; Silver Now Being Used for Chemical Plant. *Chemical Age,* **65,** 331 (1951) Sept. 8.

Describes the utilization of silver as lining on a base metal of high strength. A silver-lined, mild steel reaction vessel which is corrosion-resistant is illustrated. Table gives corrosion resistances of chemically pure silver to a series of common chemicals at temperatures from room to 70°-350°C.—BLR.

6.3.15, 3.7.1, 3.5.1

Titanium as an Engineering Material. J. L. EVERHART. *Materials and Methods* (U. S. A.), **34,** No. 6, 91-94 (1951) Dec.

Large scale production of titanium is carried out by the Kroll process. The metal produced by this process is in sponge form, and must be melted or compacted by some means to obtain a massive product for further working. The melting point of the metal is higher than any of those metals presently in use for construction purposes. The modulus of elasticity is only half that of steel. Titanium is a reactive metal, allowing for considerable modification in its properties during melting. It is resistant to oxidizing acids and dilute alkalies. It is practically immune to attack by sea water. Commercial titanium can be fabricated by bending, spinning, drawing or similar operations. It can be forged at temperatures of 1500° to 1700° F. Low carbon-oxygen-nitrogen titanium carbide deep drawn as readily as stainless steel or nickel. Titanium work hardens rapidly and a tough springy chip is produced when it is machined. Tungsten carbide tools give the best results. Titanium is difficult to saw, particularly in heavy sections, and a heavy positive cut is desirable. Drilling and tapping are more difficult because of the tendency of the metal to weld to the tool. For surface grinding, best results are obtained with aluminia wheels and low wheel speeds of 2000 to 3000 sfpm.

The crystal structure of titanium changes at 1625°F from hexagonal close-packed

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to body-centered cubic. In the alloys of the metal, this transformation means that annealing can be accomplished in a short enough period that there will be no danger of embrittlement. Conventional degreasing methods can be employed for cleaning titanium. It can be welded to itself by resistance or inert-arc methods, but a satisfactory process for joining titanium to other metals has not yet been developed. The difficulties encountered in welding are similar to those of aluminum and magnesium. It can be brazed to dissimilar metals using titanium-copper or manganese-nickel alloys as the brazing materials. Commercial titanium is in use for corrosion resistant equipment in the chemical process industries. Its high resistance to corrosion by sea water will lead to wide application in the marine industry.—ALL.

6.3.15, 3.5.9, 3.4.6

How Does Titanium Scale at High Temperatures? P. H. MORTON AND W. M. BALDWIN, JR. *Iron Age*, **169**, 133-138 (1952) May 1.

At 850° to 1000°C a transition from a primary light scale to a black scale was observed with the U. S. Bureau of Mines titanium that has not been reported previously. This oxidation product was composed of five layers and was accompanied by a change from a low scaling rate to a much higher one. Above 1000°C behavior was more complex. Titanium from two other sources was the same in appearance and overall reactions were also similar, except that no transition occurred. (Auth.).—NSA.

6.3.15, 3.7.2, 3.7.4

The Effect of the Elements of the First Long Period on the Transformation in Titanium. A. D. MCQUILLAN. *J. Inst. Metals*, **80**, Pt. 7, 363-368 (1952) Mar.

The method in which the hydrogen pressure in equilibrium with an extremely dilute solution of hydrogen in a titanium-rich alloy is measured as a function of temperature in order to follow the phase transformations occurring in the alloy was used for a systematic investigation of the effects of vanadium, chromium, manganese, nickel, and cobalt (the maximum amount of each element was about 5 atomic percent) on the $\alpha \rightleftarrows \beta$ transformation in Ti. With the exception of vanadium, these elements (all of these elements when added to titanium, depress the allotropic transformation) are not appreciably soluble in the low-temperature (α) form of titanium. The extent of the depression of the $\beta/(\alpha+\beta)$ boundary is substantially the same for equal atomic fractions of all the addition elements, except in the case of vanadium, which is slightly less effective in this respect. The experimentally determined $\beta/(\alpha+\beta)$ boundaries were compared with an idealized theoretical boundary obtained from the known latent heat of transformation of pure titanium. The experimental data were used to determine the effect of addition elements on the hydrogen solubility in β-titanium. Vanadium caused the greatest change in this property, the other elements having but little effect. Six references.—INCO.

6.3.15, 6.3.13, 6.3.9, 6.3.20

The Corrosion Resistance of Some "Minor" Metals: A Review of the Available Information. *Metal Ind.* (London), **(80),** Nos. 5-6, 83-85, 111-113 (1952) Feb. 1, 8.

The first section discusses the behavior of titanium towards a number of acids and other media, and 89-11 titanium-chromium towards few reagents. Second part deals with zirconium, molybdenum, tantalum and tantalum-molybdenum alloys. Twelve literature references are quoted.—BNF.

6.3.15, 8.9.1

Titanium in Aircraft Production. W. S. COCKRELL, Ryan Aeronautical Aircraft Co. *Light Metal Age*, **9**, No. 11-12, 10-12 (1951) Dec.

Discussion of the experimental production procedure established by the Ryan Laboratory to determine the behavior of titanium when welded, formed and heat-treated. Because titanium falls between the aluminum and steel alloys in both strength and resistance to temperature, it is the answer to many of the aircraft designer's problems. Development of titanium and high temperature deterioration are discussed. Photographs and diagrams are included.—INCO.

6.3.19, 3.2.2, 2.4.3

Experience of Intercrystalline Corrosion of Zinc Alloys. (In Swedish.) W. BROBERG. *Publication of Iva* (Sweden), **22**, No. 5, 169-171 (1951) 1000 Words.

The author refers to the substitution, which took place between the two world wars, of zinc alloy die castings for hot brass pressings in small gears used in the telephone system. Both axial and radial dimensional increases led to seizure of the mechanism, and these faults were traced to intercrystalline corrosion due to certain metallic impurities of which tin was the worst offender. By using high purity alloys, intercrystalline corrosion was avoided. Spectrographic methods of analysis to maintain good control of alloy composition are recommended.—ZDA.

6.3.20, 3.2.3, 3.8.4

The Corrosion of Zirconium. L. E. COLTERYAHN, W. JOSEPH, W. E. RAY, AND H. J. READ. Pennsylvania State College. Dec. 31, 1951. 17 p.

Thin films of zirconium satisfactory for corrosion studies have been obtained by cathodic sputtering onto electropolished copper foil. The conditions which had been previously reported as yielding continuous films remain unchanged. A preliminary x-ray study indicated that some difference in crystal structure results when zirconium oxide is prepared from the hydroxide which has been precipitated from an aqueous solution with sodium hydroxide or ammonium hydroxide and subsequently ignited. The rate of oxidation of zirconium at elevated temperatures has been found to increase very rapidly in the presence of water vapor. Up to the present time, very little success has been attained in the preparation of magnesium single crystals which would be satisfactory as basis metals for the growth of single-crystal films of zirconium by epitaxy. (Author.)—N.S.A.

6.3.20, 3.2.3, 3.8.4

The Corrosion of Zirconium. L. E. COLTERYAHN, W. E. RAY, AND H. J. READ. Pennsylvania State College. Sept. 31, 1951. 14 p.

Thin films of zirconium which are to be used in corrosion studies have been prepared by cathodic sputtering. Dense, continuous films were obtained in 10 hr.

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at a cathode current density of 0.014 ma/mm² in an atmosphere of Krypton at 140 to 180 μ pressure. The apparatus used is diagramed. Furnaces for contamination of pure films with gaseous impurities and for the corrosion of specimens in gaseous corrosive atmospheres and the procedures to be used are described.—NSA.

6.3.20, 3.7.2

Corrosion Resistance of Zirconium: Effect of Oxygen, Nitrogen, Carbon, and Hafnium. R. J. BRUMBAUGH. *Ind. and Eng. Chem.*, **43**, No. 12, 2878-2880 (1951) Dec.

Using the de Boer process, Foote Mineral Co. is now producing high-purity ductile zirconium (containing less than 0.1% hafnium but not free from oxygen, nitrogen or carbon) commercially. Gives results of corrosion tests on this material to which additional amounts of oxygen, nitrogen, and carbon had been added, and also on ordinary hafnium-bearing zirconium iodide, titanium and magnesium-reduced titanium. Media used included sulfuric acid, hydrochloric acid, nitric acid, sodium hydroxide, sodium chloride, ammonium hydroxide, and mixed acids. The contaminants were found to lower the corrosion resistance of zirconium; the high purity metal had good resistance to fuming nitric acid.—BNF.

6.4 Non-ferrous Metals and Alloys—Light

6.4.2, 5.3.2, 2.2.2

Corrosion Tests on Aluminum Alloy Sheet Clad With an Aluminium Coating of 99.36 Per Cent Purity. C. BRAITHWAITE. *Selected Government Research Reports* (England) **3**, Protection and Electro-Deposition of Metals, pages 255-259, His Majesty's Stationary Office, London, 1951.

Results of tests showed that no appreciable loss of mechanical properties with 99.5 percent or 99.36 percent aluminum coating occurred as a result of corrosion. Corrosion was, however, more severe with these materials than with a purer cladding material. For this reason, only the latter should be used for parts subjected to severe conditions. The specimens were exposed to the intermittent sea-water spray test at R.A.E. and at Bangor. Both sets of specimens were exposed over a period of one year. Specimens to Specification D.T.D. 390 with coatings of not less than 99.5 percent purity were also exposed for comparison purposes. At the conclusion of the corrosion tests, visual and microscopical examinations were made. The tensile strength of the specimens was examined after exposure and compared with that of the uncorroded material.—ALL.

6.4.2, 3.2.3

Corrosion Problems with Aluminum and Its Alloys. V. CHRISTIANSEN. *Proc. Royal Swedish Academy Engineering Sciences* (Sweden), **22**, No. 4, 103-113 (1951).

A brief report on how aluminum and its alloys are affected by corrosion. It deals with the oxide layer formed on the aluminum surface and its effects, the influence on corrosion resistance of compounds and alloy additions, the influence of heat treatment, various forms of corrosion, and how aluminum is affected by attacks of various kinds of atmosphere, different waters and some chemicals.—ALL.

6.4.2, 3.7.1, 3.8.4

Some Researches of the "Commission Francaise des Etats et Proprietes de surface des Metaux" [on Aluminium and Its Alloys]. GEORGES CHAUDRON. *Bull. Soc. Roy. Belge Ing. Ind.*, No. 6, 261-270 (1951).

The following matters relating to metals, and more especially to aluminum, are briefly discussed: effects of mechanical polishing upon the surface structure (Beilby layer); examination of metal surface by reflected X-rays; chemical perturbations produced by mechanical and electrolytic polishing; kinetic study of the oxidation of aluminum; role of surface states in corrosion phenomena; anodic oxidation of aluminum alloys; very thin oxidation films; defects revealed by anodic oxidation. In conclusion, Chaudron considers that all the properties of aluminum in working, heat-treatment, are conditioned by the surface skin of the metal. To obtain a perfect skin necessitates a sequence of metallurgical operations starting with metal of very high purity. An aluminum alloy, especially suitable for anodic oxidation and containing 3-5% magnesium, in which the α phase is entirely homogeneous, and the structure statistically isotropic, i.e. constituted of small crystals having all possible orientations, is suggested. Anodic oxidation can reveal metallic anisotropy, and is an extremely sensitive means of revealing the structure of aluminum and its alloys. 21 references.—MA.

6.4.2, 8.3.5, 8.8.1, 1.6

Aluminum in the Chemical and Food Industries. British Aluminium Co. Ltd. Publication No. 408, 1951, 149 pp. Published by the Company, Salisbury House, London Wall, London, E.C.2.

This succeeds the earlier volume of the same name issued in 1936 under the auspices of the International Aluminium Bureau. There are three chapters, dealing respectively with the general properties of the metal and its alloys (choice of material, fabrication, jointing, surface treatment, assembly); the action of numerous substances (inorganic, organic, foods and others); and methods of testing corrosion resistance.—BNF.

6.4.2, 3.5.8

Deformation and Corrosion of Aluminum. *Chemical Age* (England), **65**, No. 1667, 299 (1951) Sept. 1.

Specimens of aluminum were annealed in potassium nitrate at 450°C (840°F), for 40 minutes, cooled in air and etched in 5 percent NaOH solution at 60°C (140°F), then worked up in concentrated nitric acid. Products of corrosion were removed and tests made in two solutions: 0.3 molar hydrochloric acid and 0.5 molar sodium chloride. In the first the metal corroded with evolution of gaseous hydrogen and in the second at cathodic areas of the surface, there was acidic depolarization. The results for the hydrochloric acid tests showed that up to an increase in load equalling 25 percent yield strength corrosion rate increases; but further increase in load is practically without effect. In the sodium chloride tests there was little or no change up to 70 percent yield strength, but from that point up to 90 percent,

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corrosion rate increased. It is possible that there was a breakdown of the oxide film, and that corrosion is accompanied by hydrogen evolution.—ALL.

6.7 Duplex Materials

6.7.2, 3.4.6, 3.5.9

A Preliminary Study of the Oxidation and Physical Properties of TiC-Base Cermets. CLINTON C. MCBRIDE, HAROLD M. GREENHOUSE, AND THOMAS S. SHELVIN. *J. Am. Ceramic Soc.*, **35**, 28-32 (1952) Jan. 1.

The titanium carbide base cermets investigated contained chromium, iron, cobalt, nickel, nickel-aluminum, ferrosilicon, or duriron as the metallic constituent. They were evaluated on the basis of strengths at 75° and 1800°F, oxidation resistance at 2000°F, and degree of chemical reaction between carbide and metal as determined metallographically. Metallographic and X-ray studies were conducted on the oxide layers to determine a qualitative mechanism of oxidation. Results indicate titanium carbide plus nickel-aluminum to be the most promising composition and oxygen diffusion to be the governing factor in the oxidation of the cermets studied.—MR.

6.7.2, 3.5.9

Silicon Carbide Refractories Used as Alternates for Special Service Alloys. J. L. EVERHART. *Materials & Methods*, **34**, No. 5, 71-75 (1951) Nov.

Combination of good elevated temperature properties, and high abrasion and corrosion resistance fits silicon carbide for numerous applications where strategic alloys were formerly used. As a substitute for heat resisting alloys in World War II, bonded silicon carbide proved so satisfactory that it displaced the metal permanently. Comparison of the properties of several heat resisting steels, fire clay brick, and silicon carbide brick is made and applications of silicon carbide refractories are listed.—INCO.

7. EQUIPMENT

7.1 Engines, Bearings, and Turbines

7.1, 4.4.7, 6.5

Corrosive Effects of Motor Gear Oils (on Copper and Steel). (In German.) A. BUKOWIECKI. *Schweiz. Arch. angew. Wiss. u. Tech.*, **17**, No. 6, 182-191 (1951).

Tests have been carried out to determine the possible corrosive effects of 9 motor gear oils, some chlorinated, others non-chlorinated, commonly used in Switzerland. Extreme-pressure agents of types containing sulfur chlorine, phosphorus, lead and carboxyl compounds are quite commonly added to lubricants for lubricating hypoid gears of the kinds used in American cars, where local pressures as high as 20,000 kg./cm^2 may occur in the back axle. Tests were carried out over a period of 10 days on iron and copper. The oils, heated to 80°-120°C, even after prolonged contact, attacked iron only slightly, but the chlorinated oils showed a distinct tendency to produce after-rusting effects, i.e. gear-tooth surfaces were attacked after removal from the oil and storage in an humid atmosphere. The severity of this attack depended on the type of extreme-pressure agent used. All chlorinated oils produced after-rusting effects, the amount varying very considerably with the test temperature; non-chlorinated oils produced practically no rusting. Copper was comparatively heavily attacked at 122°C by all the 9 oils, including those free from chlorine. 28 references.—MA.

7.8 Wires and Cables (non-electrical)

7.8. 8.10 3. 4.4.7

Testing Wire Rope Lubricants. L. A. BUSHELL AND P. MARAIS. *South African Mining and Engineering Journal*, **62**, 291-293 (1951) Oct. 20.

An investigation of corrosion and lubrication of wire ropes in Free State gold mines. Gives method of testing, description of apparatus, preliminary experiments, comparison of lubricants and results.—BLR.

8. INDUSTRIES

8.4 Group 4

8.4.3, 5.4.5, 5.4.3

Coated Oil-Well Pipe. *Fortune*, **43**, No. 6, 32 (1951) June.

Manufacturers of plastic coatings have been working with oil industry technicians on the use of Vinylite coatings to prevent corrosion in oil-well tubing. California Standard engineers recently completed a five month test, in which ordinary pipe was deeply corroded after being subjected to a daily flow of 100 barrels of oil and 5000 barrels of salt water high in iodine content. Vinylite-coated pipe appeared to be unaffected.

8.9 Group 9

8.9.3. 5.4.5, 7.2, 3.7.3, 6.6.8

Pipeline Techniques Advance. W. R. FINNEY, Standard Oil Company. *Oil Gas J.*, **50**, No. 22, 174-176+ (1951) Oct. 4.

In spite of advances made in recent years, a need still exists for a new synthetic coating which can be applied at the mill, be durable enough for all the handling and still protect pipe surfaces against external corrosion. Fiber-glass-reinforced plastic pipe as a substitute for steel is used for many purposes, but there is a necessity for developing a readily applied field joint which would be as strong as the pipe itself and would not interfere with handling or laying of the pipe.—INCO.

8.10 Group 10

8.10.2, 6.2.1, 1.6

Steel Castings Handbook. CHARLES W. BRIGGS, Editor. 6 x 9 inches, 511 pages plus v, fabrikoid cover. June, 1950. Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio. Per Copy, $4.00.

This well-illustrated book contains a large quantity of tabulated data and numerous references. It deals with the whole scope of the steel castings industry, enumerating the classes and advantages of steel castings, commercial and industrial applications, design, manufacturing methods, heat treatment, variables affecting the mechanical properties, mechanical properties of carbon cast steels, heat and corrosion resistant cast alloys, austenitic manganese cast steel, physical values pertaining to cast steel, engineering properties, recommendations to purchasers of castings, specifications, definitions of foundry terms and chemical compositions of standard steel.

This revision of the 1941 edition in the chapter dealing with heat and corrosion resistant cast alloys deals generally with the various principal classes of cast metals for corrosive and high temperature service. Typical applications of several principal alloy types are tabulated, and the factors to be weighed in selecting a corrosion resistant alloy are given. General characteristics of the heat resistant alloys are listed and tables are given showing the mechanical properties of principal corrosion resistant alloys at room and high temperatures.

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